MARYLAND
DEPARTMENT OF
NATURAL RESOURCES

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LIDAR 2003
Quality Assurance Report

Authored by Dewberry LLC
2003

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Introduction

As part of the Spatial Systems Associates team, Dewberry's role is to assess the quality of the LIDAR as flown by Airborne 1 (A1) and processed by Computational Consulting Services (CCS) in 2003. Dewberry's business model and reputation for LIDAR assessment is rooted in performing independent quality assurance and quality control (QA/QC). By maintaining independence, Dewberry is not influenced by external factors, thereby allowing unbiased reporting of the data as tested.

As stated, the LIDAR assessment contains both quantitative and qualitative reviews. The quantitative assessment utilized ground truth surveys which are compared to the LIDAR data. The results are then reported based on FEMA Guidelines and Specifications for Flood Hazard Mapping Partners (Appendix A: Guidance for Aerial Mapping and Surveying), and by the testing guidelines of the National Digital Elevation Program (NDEP), using methods developed by Dewberry for both of these programs. The qualitative assessment utilizes interpretive and statistical methods based on the level of cleanliness for a bare-earth terrain model.

The project area for assessment encompassed seven partial coastal counties in eastern Maryland. Figure 1 illustrates the project area with the tiles that contain checkpoints highlighted in red.

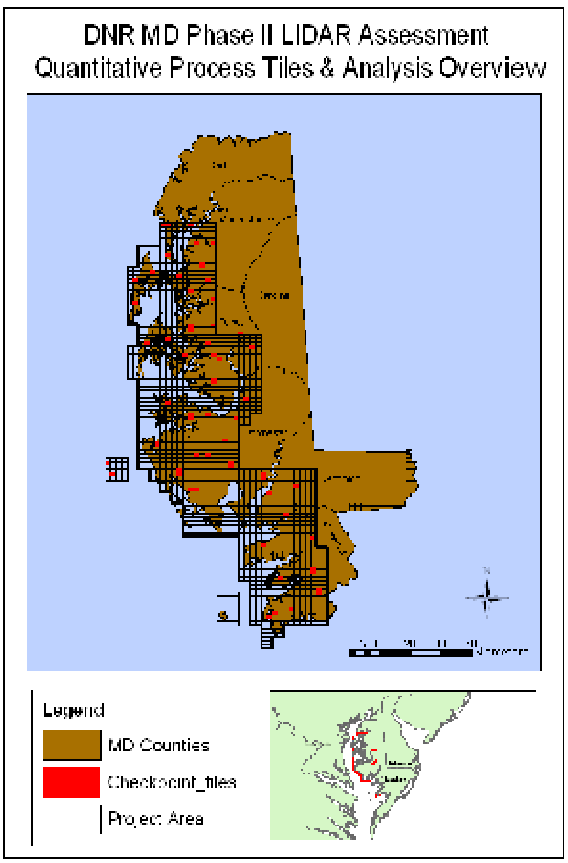

Figure 1 – Overview of Project Area.

Fundamental Review of LIDAR Data

Within this review of the LIDAR data, two fundamental questions were addressed:

1. Did the LIDAR system perform to specifications?
2. Did the vegetation removal process yield desirable results for the intended product?

In order to assess whether or not the system obtained accurate elevation data, only open terrain areas were evaluated. The principle here is if the data were to be measured in open terrain, the pulse of energy emitted by the sensor would be detected as a strong peak in reflected light. Since the laser light would not be influenced by the filtering through vegetation (which would cause many return pulses), the mathematics could easily identify the "last peak pulse" return of the laser, thereby obtaining an accurate delta elevation between the sensor and the target. Using the geo-referenced position of the aircraft, coupled with that of the sensor data, an accurate elevation is obtained. It should be noted that any discrepancies of the elevation does not definitively conclude that the system did not perform to specification as the system could obtain excellent "relative position" accuracies but weak "absolute position" accuracies. Relative position accuracies are defined as true delta heights between the aircraft and the target being measured. A scenario could exist whereby the relative accuracies are good, but the absolute positional accuracy of the aircraft is in error. This could be caused by factors such as inconsistent survey control values, blunders in antenna heights, systematic biases due to tropospheric modeling, geoid modeling, etc. However, the quantitative testing typically identifies "absolute" inaccuracies.

Using only the checkpoints in open terrain, the land cover "Grass/Ground" had an RMSE of 13.7 cm using all of the checkpoints without discarding any outliers. This is a very clear indication that the system performed to specification, especially regarding absolute positional accuracy. It should be noted that although the land cover category of "Urban/Pavement" could be considered open terrain, it is not open terrain since this includes sidewalks and roadways. This is due to the wavelength of the LIDAR system and the ability of asphalt to absorb the laser light yielding slightly lower elevations. Also built-up areas that include structures can introduce some multi-path of the LIDAR near building edges, again lowering the elevations slightly.

Since the data exhibited accurate results for open terrain areas, it is conceivable that the results would be similar to not only the surface model (first return), but also the terrain model (last return) as long as the LIDAR could penetrate the openings of vegetation and produce a strong enough return. It is at this stage that the vegetation removal process is employed, yielding a bare-earth terrain product. The process of removing artifacts which consists of vegetation and man-made structures is complicated due to the complexity of geographic phenomena. A balance must be struck between removing artifacts while maintaining the integrity of the bare-earth. For example, if too aggressive editing is employed along a tree-lined stream embankment, the potential could be that the stream channel geometry is enlarged or the height of the top of stream bank is erroneously lowered (over-smoothed). This could yield improper results for hydraulic modeling for flood studies. Conversely, if artifacts are left behind, this to can cause errors in modeling especially if it indicates that these features would impede the flow of water. It is then imperative to answer the fundamental question number 2; "Did the vegetation removal process yield desirable results?"

Both these questions can be answered using a combination of quantitative and qualitative review processes.

Quantitative Analysis – Checkpoint Survey

As outlined in the initial proposal and assessment report, the vertical accuracy of the LIDAR data (ground-truthing) was to be performed by surveying checkpoints in strategic locations. These checkpoint surveys were to follow the locational criteria as set forth by the FEMA Guidelines and Specifications for Flood Hazard Mapping Partners (Section A.6.4 of Appendix A: Guidance for Aerial Mapping and Surveying), and by the testing guidelines of the National Digital Elevation Program (NDEP), using methods developed by Dewberry for both these programs. The first part of this process is to base the number of checkpoints on the number of major land cover categories representative of the area being mapped. The example given was that if 5 categories represented the major land cover categories, then a minimum of 20 checkpoints would be measured for each of these land cover categories, for a total of 100 checkpoints.

A total of 140 checkpoints were submitted for the LIDAR analysis by an independent surveyor. From this total amount, 121 were found to be usable and within the areas of submitted LIDAR data. Since there were five land cover categories, this number exceeded the required amount of 100 checkpoints. The derivation of 20 checkpoints per land cover category is from paragraph 3.2.2 of the National Standard for Spatial Data Accuracy which states: "A minimum of 20 check points shall be tested, distributed to reflect the geographic area of interest and the distribution of error in the dataset.[4] When 20 points are tested, the 95% confidence level allows one point to fail the threshold given in product specifications." Footnote 4 refers the reader to Section 3 of Appendix 3-C which states: "Due to the diversity of user requirements for digital geospatial data and maps, it is not realistic to include statements in this standard that specify the spatial distribution of check points. Data and/or map producers must determine check point locations. This section provides guidelines for distributing the check point locations. Check points may be distributed more densely in the vicinity of important features and more sparsely in areas that are of little or no interest. When data exist for only a portion of the dataset, confine test points to that area. When the distribution of error is likely to be nonrandom, it may be desirable to locate check points to correspond to the error distribution." However, the NSSDA does not address the size of the project area which could mean a few acres to thousands of square miles. Even though the data has been tested as per specification, further review may be warranted by intended users to verify that the data will meet their needs.

Figure 2 illustrates the geographic location of the checkpoints relative to the project area. It should be noted that the checkpoints encompass a large area and are in strategic geographic locations spread out to verify as much of the data as possible. Since the flight lines consisted of smaller flight line blocks of the project area, the location of the checkpoints help verify the data from different flights.

Just as important as the geographic location of the checkpoint, the "locale" also plays a significant role. Since the comparison of the checkpoints cannot be in exactly the same locations as the LIDAR points (if the checkpoints are measured without any prior knowledge of the

LIDAR point locations), interpolation methods must be incorporated and accounted for. Therefore, the comparison is truly between the checkpoints and the terrain model, i.e., the Triangular Irregular Network (TIN) of the bare-earth terrain model. Care must be taken to assess the slope of the checkpoint locations since the checkpoints are verifying the LIDAR. Checkpoints located on a high slope could falsely accuse the LIDAR data of being inaccurate. The outline for the Independent Surveyor was to establish checkpoints on as level terrain as possible within a 5 meter radius. The secondary criteria was that the slope be less than 20% (preferably less than 10%) and at least 5 meters away from any breaklines, as specified in sections A.6.4, Appendix A to FEMA's Guidelines and Specifications; this same criteria for selection and location of checkpoints has been adopted by the National Digital Elevation Program (NDEP) which has submitted its recommendations to the Federal Geographic Data Committee (FGDC) for adoption in the next revision to the National Standard for Spatial Data Accuracy (NSSDA). If the LIDAR indicates a high slope, but there is confidence that the checkpoint is on fairly level ground, this could indicate an error within the LIDAR. For the 121 checkpoints, 5 were greater than 10% but less than 16%. Thus, there was no reason to question the checkpoint locations.

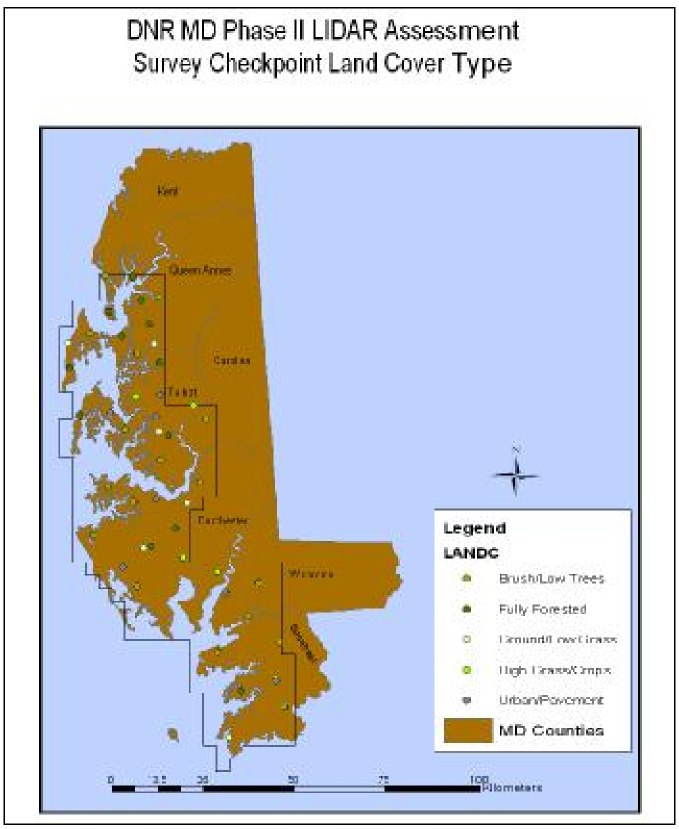

Figure 2 – Survey checkpoint locations and land cover type.

Table 1 lists the survey checkpoints with their associated slope values. Also, since checkpoints are being used to evaluate the terrain "surface", the distance between the checkpoints and the closest LIDAR point is evaluated. A stronger confidence level will exist knowing the distance between the two discrete measurements. In areas of high vegetation larger numbers are not only expected but warranted. In most cases, the distance is less than 2 meters which is ideal.

Surveyor Checkpoints – Delta Elevations – Distance to Closest LIDAR Point - Slope						
Pt Number or Name	**LandClass**	**QA/QC Elevation(m)**	**LIDAR Elevation(m)**	**Elevation Difference(cm)**	**Dist to LIDAR (m)**	**Slope (%)**
299	Ground/Low Grass	17.143	16.890	-25.3	0.70	2.0
2	Ground/Low Grass	1.274	1.120	-15.4	0.33	7.2
231	Ground/Low Grass	0.855	0.730	-12.5	0.51	4.1
258	Ground/Low Grass	5.871	5.750	-12.1	0.77	4.6
249	Ground/Low Grass	2.287	2.180	-10.7	1.22	5.5
228	Ground/Low Grass	4.213	4.110	-10.3	0.95	2.6
207	Ground/Low Grass	2.091	2.010	-8.1	0.56	5.7
222	Ground/Low Grass	0.901	0.830	-7.1	0.50	7.7
254	Ground/Low Grass	1.540	1.470	-7.0	0.24	11.7
245	Ground/Low Grass	0.728	0.700	-2.8	0.87	6.3
213	Ground/Low Grass	0.583	0.610	2.7	0.88	2.3
CRISFIELD	Ground/Low Grass	1.207	1.240	3.3	0.50	3.6
259	Ground/Low Grass	8.950	8.990	4.0	1.07	4.5
242	Ground/Low Grass	3.436	3.480	4.4	1.09	4.2
310	Ground/Low Grass	12.306	12.360	5.4	0.17	2.7
318	Ground/Low Grass	8.415	8.500	8.5	0.34	9.0
SLATTS	Ground/Low Grass	16.796	16.900	10.4	0.82	2.0
271	Ground/Low Grass	4.195	4.300	10.5	0.41	3.9
265	Ground/Low Grass	2.643	2.770	12.7	1.08	4.4
127	Ground/Low Grass	8.312	8.440	12.8	0.49	5.2
278	Ground/Low Grass	15.755	15.890	13.5	0.53	2.7
315	Ground/Low Grass	20.447	20.600	15.3	0.65	3.9
268	Ground/Low Grass	2.118	2.280	16.2	1.03	2.0
219	Ground/Low Grass	0.627	0.790	16.3	0.21	1.3
291	Ground/Low Grass	1.610	1.790	18.0	0.11	3.2
314	Ground/Low Grass	18.026	18.220	19.4	0.58	4.5
262	Ground/Low Grass	11.305	11.560	25.5	0.84	4.5
MAT	Ground/Low Grass	4.761	5.020	25.9	0.41	4.5
282	High Grass/Crops	11.312	11.090	-22.2	0.37	4.8
298	High Grass/Crops	15.204	15.010	-19.4	0.74	4.4
255	High Grass/Crops	1.400	1.310	-9.0	1.20	6.4
237	High Grass/Crops	0.369	0.290	-7.9	1.31	5.1
240	High Grass/Crops	0.262	0.230	-3.2	0.23	2.9
216	High Grass/Crops	4.218	4.200	-1.8	0.36	8.7
292	High Grass/Crops	1.262	1.250	-1.2	0.57	4.8
233	High Grass/Crops	0.249	0.240	-0.9	0.49	5.8
305	High Grass/Crops	4.137	4.150	1.3	0.51	9.5
296	High Grass/Crops	4.907	4.960	5.3	0.93	6.3
239	High Grass/Crops	0.266	0.320	5.4	0.46	6.8
311	High Grass/Crops	18.987	19.050	6.3	0.90	5.0
308	High Grass/Crops	8.072	8.140	6.8	1.03	4.8
287	High Grass/Crops	2.417	2.490	7.3	0.30	4.4
263	High Grass/Crops	11.356	11.430	7.4	0.33	4.6
225	High Grass/Crops	4.055	4.130	7.5	0.71	3.8

Surveyor Checkpoints – Delta Elevations – Distance to Closest LIDAR Point - Slope						
Pt Number or Name	**LandClass**	**QA/QC Elevation(m)**	**LIDAR Elevation(m)**	**Elevation Difference(cm)**	**Dist to LIDAR (m)**	**Slope (%)**
243	High Grass/Crops	3.347	3.460	11.3	0.46	5.8
272	High Grass/Crops	4.308	4.430	12.2	0.70	5.3
212	High Grass/Crops	0.485	0.620	13.5	0.80	4.2
210	High Grass/Crops	3.672	3.820	14.8	0.65	2.4
269	High Grass/Crops	2.157	2.320	16.3	0.33	3.9
285	High Grass/Crops	19.476	19.670	19.4	0.73	6.9
274	High Grass/Crops	20.761	21.140	37.9	0.70	15.4
300	Brush/Low Trees	11.336	11.110	-22.6	0.99	12.5
261	Brush/Low Trees	9.069	8.900	-16.9	0.36	4.2
229	Brush/Low Trees	4.191	4.050	-14.1	0.24	2.3
250	Brush/Low Trees	2.317	2.290	-2.7	1.35	8.0
306	Brush/Low Trees	4.046	4.040	-0.6	0.27	8.7
206	Brush/Low Trees	2.360	2.370	1.0	1.14	2.4
234	Brush/Low Trees	0.326	0.380	5.4	0.98	5.8
293	Brush/Low Trees	1.625	1.710	8.5	0.86	3.8
252	Brush/Low Trees	1.501	1.590	8.9	0.77	3.7
289	Brush/Low Trees	3.368	3.460	9.2	1.05	5.0
270	Brush/Low Trees	2.027	2.120	9.3	2.33	3.0
321	Brush/Low Trees	9.674	9.770	9.6	0.77	4.2
312	Brush/Low Trees	11.093	11.200	10.7	0.42	5.5
246	Brush/Low Trees	0.800	0.910	11.0	0.37	1.7
241	Brush/Low Trees	0.370	0.530	16.0	1.49	3.5
223	Brush/Low Trees	0.540	0.720	18.0	0.74	5.1
217	Brush/Low Trees	0.907	1.100	19.3	0.32	9.1
264	Brush/Low Trees	7.248	7.450	20.2	0.79	3.3
316	Brush/Low Trees	16.862	17.090	22.8	0.46	4.8
220	Brush/Low Trees	0.411	0.700	28.9	0.98	3.8
279	Brush/Low Trees	15.532	15.870	33.8	0.16	4.8
301	Brush/Low Trees	3.584	3.940	35.6	0.63	7.6
284	Brush/Low Trees	19.789	20.230	44.1	0.17	4.7
256	Fully Forested	1.810	1.710	-10.0	0.88	3.5
235	Fully Forested	0.646	0.550	-9.6	1.66	2.1
238	Fully Forested	0.498	0.540	4.2	0.78	3.0
208	Fully Forested	1.945	2.010	6.5	0.31	4.8
290	Fully Forested	1.704	1.780	7.6	1.02	6.0
244	Fully Forested	3.579	3.670	9.1	2.13	5.7
232	Fully Forested	0.580	0.690	11.0	1.08	4.4
253	Fully Forested	1.065	1.190	12.5	1.44	4.8
297	Fully Forested	1.471	1.620	14.9	2.11	1.4
294	Fully Forested	1.537	1.710	17.3	0.61	8.1
226	Fully Forested	3.073	3.280	20.7	2.80	5.1
320	Fully Forested	9.372	9.580	20.8	6.07	4.0
317	Fully Forested	17.514	17.730	21.6	0.96	6.2
273	Fully Forested	4.122	4.340	21.8	1.87	2.2
276	Fully Forested	19.932	20.150	21.8	5.10	1.5

Surveyor Checkpoints – Delta Elevations – Distance to Closest LIDAR Point - Slope						
Pt Number or Name	LandClass	QA/QC Elevation(m)	LIDAR Elevation(m)	Elevation Difference(cm)	Dist to LIDAR (m)	Slope (%)
247	Fully Forested	0.441	0.670	22.9	0.83	3.6
309	Fully Forested	2.298	2.560	26.2	0.46	4.7
286	Fully Forested	19.499	19.770	27.1	1.29	2.3
313	Fully Forested	11.401	11.680	27.9	0.97	2.3
267	Fully Forested	2.207	2.490	28.3	0.62	5.3
214	Fully Forested	0.506	0.900	39.4	0.48	2.6
211	Fully Forested	3.892	4.360	46.8	1.07	4.0
303	Fully Forested	3.532	4.030	49.8	2.03	0.2
227	Urban/Pavement	4.715	4.610	-10.5	0.65	4.9
248	Urban/Pavement	2.971	2.890	-8.1	0.58	2.6
224	Urban/Pavement	3.216	3.210	-0.6	1.08	7.5
236	Urban/Pavement	0.644	0.640	-0.4	0.78	5.0
295	Urban/Pavement	2.242	2.270	2.8	0.57	1.3
260	Urban/Pavement	9.536	9.570	3.4	0.15	12.8
319	Urban/Pavement	6.778	6.820	4.2	0.61	3.4
257	Urban/Pavement	5.780	5.830	5.0	0.68	3.1
288	Urban/Pavement	3.224	3.280	5.6	0.91	5.5
302	Urban/Pavement	3.709	3.770	6.1	0.52	6.3
209	Urban/Pavement	4.215	4.280	6.5	0.67	1.2
304	Urban/Pavement	2.925	2.990	6.5	0.85	2.4
221	Urban/Pavement	0.820	0.900	8.0	0.33	8.2
283	Urban/Pavement	2.167	2.260	9.3	0.66	10.7
275	Urban/Pavement	19.156	19.250	9.4	0.64	2.5
218	Urban/Pavement	0.915	1.020	10.5	0.68	4.7
230	Urban/Pavement	0.967	1.080	11.3	0.33	7.2
251	Urban/Pavement	2.472	2.600	12.8	0.74	3.8
215	Urban/Pavement	1.337	1.470	13.3	0.34	3.2
281	Urban/Pavement	7.847	7.980	13.3	0.60	3.3
266	Urban/Pavement	3.596	3.740	14.4	0.46	4.4
277	Urban/Pavement	16.428	16.610	18.2	1.12	3.8
307	Urban/Pavement	5.312	5.530	21.8	0.97	4.9
280	Urban/Pavement	16.868	17.130	26.2	0.34	3.5

Table 1 – Comparison of LIDAR minus the survey checkpoints showing delta elevations; distance from the checkpoint to the closest LIDAR point; and computed slope values of the checkpoint derived from the TIN.

Vertical Accuracy Assessment Using RMSE Methodology

The first method of testing vertical accuracy is to use the Root Mean Square Error (RMSE) approach which is valid when errors follow a normal distribution. This methodology measures the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points. The vertical accuracy assessment compares the measured survey checkpoint elevations with those of the Triangulated Irregular Network (TIN) as generated from the LIDAR. The survey checkpoint's X/Y location is overlaid on the TIN and the interpolated Z value is recorded. This interpolated Z value is then compared to the survey checkpoint Z value and this difference represents the amount of error between the measurements. The following graphs and tables outline the vertical accuracy and the statistics of the associated errors.

Table 2 summarizes the RMSE using:

- 100% of the checkpoints (method used by FEMA when errors are assumed to follow a normal distribution)
- 95% of the checkpoints ("95% clean" methodology used in Phase I of the North Carolina Floodplain Mapping Program -- NCFMP -- where errors are still assumed to follow a normal distribution but where 5% of the errors are assumed to fall in "uncleaned" areas)
- Checkpoints categorized by land cover type based on 100% of points

RMSE by Land Cover				
%	**RMSE (cm)**	**# of Points**	**Land Class**	**RMSE Criteria (cm)**
100	**16.9**	121	**All**	18.5 (FEMA methodology)
95	**14.3**	**116**	**All**	**18.5 (NCFMP Phase 1 methodology)**
23	**13.7**	28	**Grass/Ground**	
19	**13.3**	23	**High Grass/Crops**	
19	**19.5**	23	**Brush/Low Trees**	
19	**24.0**	23	**Forest**	
20	**11.3**	24	**Urban/Pavement**	

Table 2 – RMSE of LIDAR based on QA/QC survey checkpoints.

Table 2 clearly shows that 100 percent of the combined checkpoints fall within the desired and targeted RMSE of 18.5 cm, thereby satisfying FEMA requirements for the equivalency of 2 foot contours. It can also be seen that some land cover categories by themselves slightly exceed the targeted RMSE value which is not atypical with LIDAR since no "outliers" have been removed. Utilizing the North Carolina approach, 5% of the largest errors are removed in order to account for uncleaned areas and gross blunders. Statistically, the data in Table 3 not only improves overall, but also improves in the vegetated categories

RMSE by Land Cover Base on the Best 95% of the Checkpoints				
%	**RMSE (cm)**	**# of Points**	**Land Class**	**RMSE Criteria (cm)**
100	**16.9**	121	**All**	18.5 (FEMA methodology)
95	**14.3**	**116**	**All**	**18.5 (NCFMP Phase 1 methodology)**
23	**13.7**	28	**Grass/Ground**	Based on best 95% of the checkpoints
19	**11.0**	23	**High Grass/Crops**	Based on best 95% of the checkpoints
19	**16.2**	23	**Brush/Low Trees**	Based on best 95% of the checkpoints
19	**18.7**	23	**Forest**	Based on best 95% of the checkpoints
20	**11.3**	24	**Urban/Pavement**	Based on best 95% of the checkpoints

Table 3 - RMSE of LIDAR based on the best 95% of QA/QC survey checkpoints.

Figure 3 and Figure 4 graphically illustrate the RMSE by land cover category and the delta difference between the LIDAR compared to that of the survey QA/QC checkpoints.

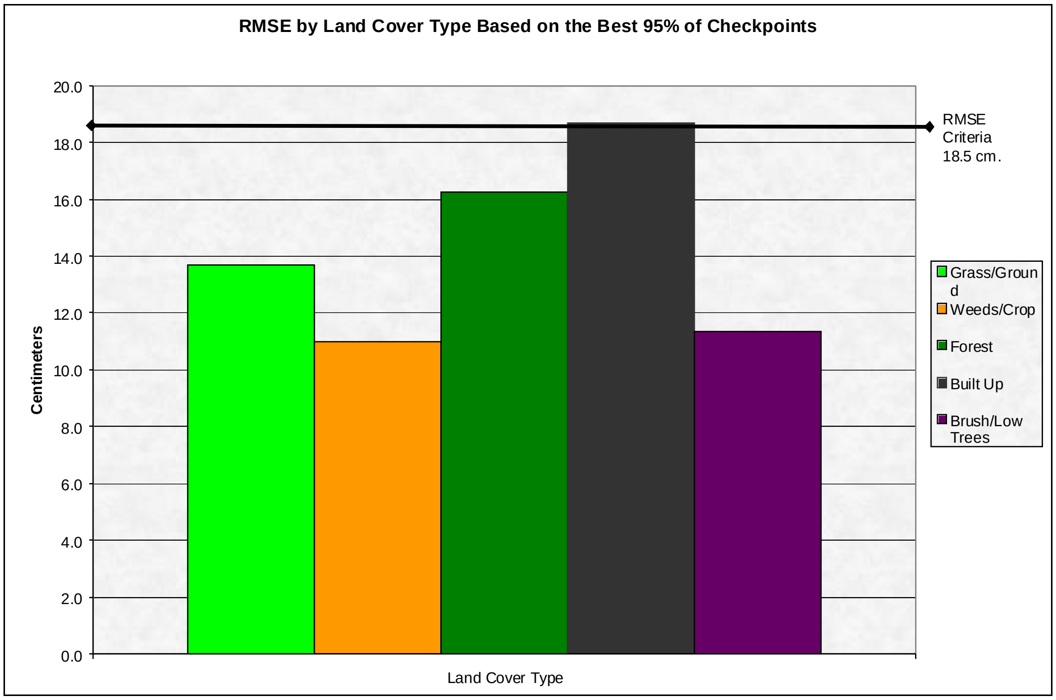

Figure 3 – RMSE by specific land cover types.

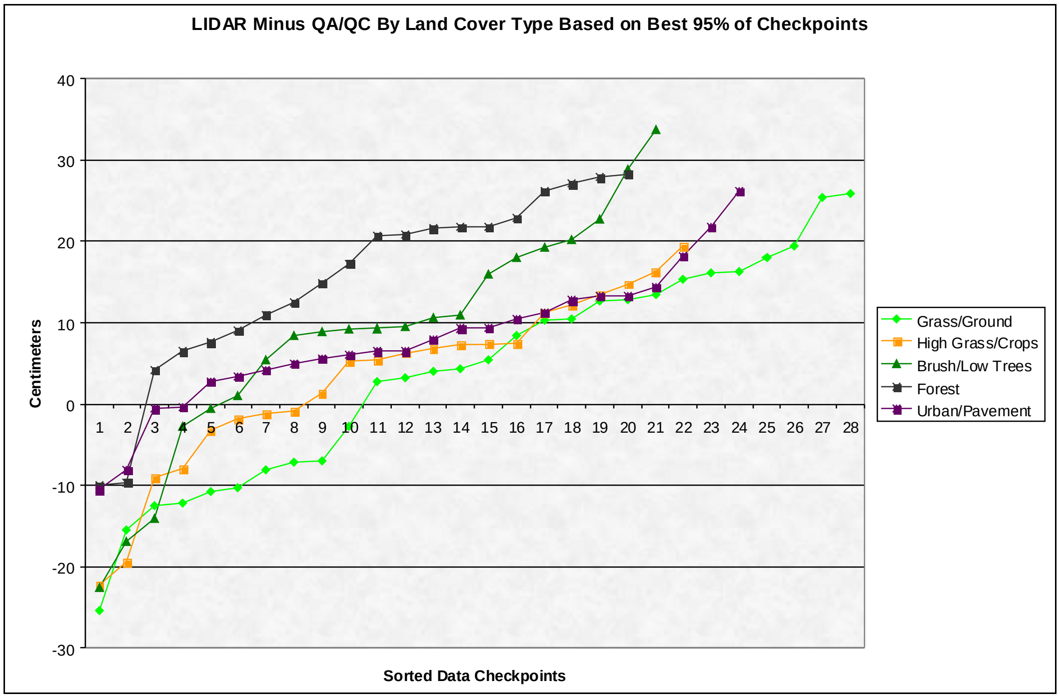

Figure 4 – Illustrates the magnitude of differences between the checkpoints and LIDAR data by specific land cover type and sorted form lowest to highest.

Table 4 summarizes the descriptive statistics referenced in the FEMA guidelines and the NCFMP reporting methodology.

Overall Descriptive Statistics								
	RMSE (cm)	Mean (cm)	Median (cm)	Skew	Std Dev (cm)	# of Points	Min (cm)	Max (cm)
100% Pts	16.9	9.1	9.2	0.1	14.2	121	-25.3	49.8
95% Pts	14.3	7.4	8.5	-0.4	12.3	115	-25.3	33.8
Grass/Ground	13.7	4.1	4.9	-0.3	13.3	28	-25.3	25.9
High Grass/Crops	11.0	3.1	5.9	-0.9	10.8	22	-22.2	19.4
Brush/Low Trees	16.2	8.4	9.3	-0.5	14.3	21	-22.6	33.8
Forest	18.7	15.1	19.0	-1.0	11.3	20	-10.0	28.3
Urban/Pavement	11.3	7.9	7.3	-0.1	8.3	24	-10.5	26.2
	Shaded cells based on the best 95% of checkpoints							

Table 4– Overall descriptive statistics.

Figure 5 and Figure 6 illustrates the histogram of the associated delta errors between the interpolated LIDAR TIN and the survey checkpoint. It is interesting to note that the errors do not follow a normal distribution. Even when the 5% largest errors are removed, the errors still do not follow a normal distribution. With this scenario where some errors do not follow a normal distribution, invalidates the RMSE methodology, the NDEP recommends that alternative criteria be used to determine the Fundamental Vertical Accuracy (mandatory) and Supplemental and Consolidated Vertical Accuracies (optional).

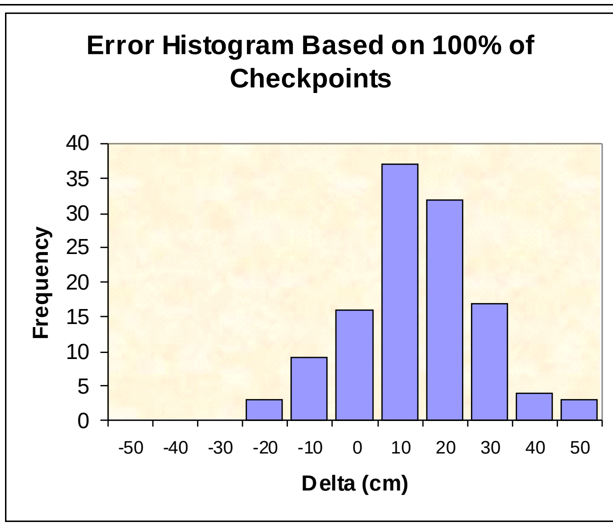

Figure 5 -- Error Histogram of the best 100% of data checkpoints.

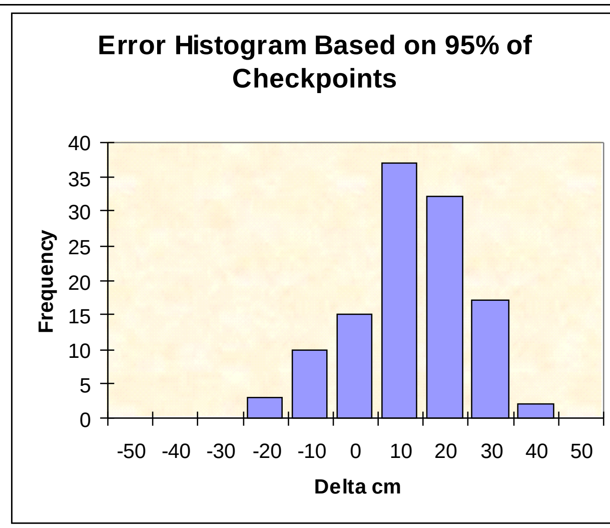

Figure 6 -- Error Histogram of the best 95% of data checkpoints.

Figure 5 and Figure 6 illustrate that the errors do not follow a normal distribution even when the top 5% of outliers are removed. It also illustrates that the LIDAR data compared to survey checkpoints tends to have a slight systematic shift, which could be in the range of 0 – 10cm.

Vertical Accuracy Assessment using NDEP Methodology

The Fundamental Vertical Accuracy at the 95% confidence level equals 1.9600 times the RMSE in open terrain only; in open terrain, there is no valid excuse why errors should not follow a normal error distribution, for which RMSE methodology is appropriate. Supplemental Vertical Accuracy at the 95% confidence level utilizes the 95th percentile error individually for each of the other land cover categories, which may have valid reasons (e.g., problems with vegetation removal) why errors do not follow a normal distribution. Similarly, the Consolidated Vertical Accuracy at the 95% confidence level utilizes the 95th percentile error for all land cover categories combined. This NDEP methodology is used on all 100% of the checkpoints and not just on the best 95% of those checkpoints.

The target objective for this project was to achieve bare-earth elevation data with an accuracy equivalent to 2 ft contours, which equates to an RMSE of 18.5 cm when errors follow a normal distribution. With this criteria, the Fundamental Vertical Accuracy of 36.3 cm must be met. Furthermore, it is desired that the Consolidated Vertical Accuracy and each of the Supplemental Vertical Accuracies also meet the 36.3 cm criteria to ensure that elevations are also accurate in vegetated areas. As summarized in Table 5, this data:

- Satisfies the NDEP's mandatory Fundamental Vertical Accuracy criteria for 2 ft contours.
- Satisfies the NDEP's optional Consolidated Vertical Accuracy criteria for 2 ft contours.
- Satisfies the NDEP's optional Supplemental Vertical Accuracy for 2 ft contours in all but one category (Forest) for vegetated areas.

Vertical Accuracy at 95% Confidence Level Based on NDEP Methodology for 2 ft contours				
Land Cover Category	**# of Points**	**Fundamental Vertical Accuracy (mandatory) 36.3 cm standard**	**Consolidated Vertical Accuracy (optional) 36.3 cm standard**	**Supplemental Vertical Accuracy (optional) 36.3 cm standard**
Grass/Ground	28	**26.9**		
High Grass/Crops	23			**21.9**
Brush/Low Trees	23			**35.4**
Forest	23			**46.1**
Urban/Pavement	24			**21.3**
Total Combined	**121**		**33.8**	

Table 5 - Vertical Accuracy per NDEP Methodology

As outlined above, the data exceeds every criteria except for the optional supplemental vertical accuracy for the land cover forest. In most forest types this is to be expected due to thickness of the canopy and the amount of under-growth. Statistically, the land cover forest has a mean delta of 19.1 cm and to further the argument, only three points are considered outliers at 39.4, 46.8, 49.8 cm. When satisfying a 2' contour interval requirement, it is normal for 5% of the checkpoints (6 of 121 checkpoints in this example) to exceed the 36.3 cm accuracy standard; here, only 3 of 121 checkpoint discrepancies exceeded 36.3 cm.

Survey Conclusion

Utilizing the multiple testing methods it is clear that the data exceeds all mandatory criteria. The data also exhibits strong results for the NDEP's <u>optional</u> criteria except in forest where it the values are elevated in comparison to other land cover categories. Since the data is typically tested on the whole dataset with all land cover categories, the higher values of the forest are averaged with the lower values from the other land cover categories. No remote sensing technology other than LIDAR, can achieve this accuracy especially in vegetated areas. Easily stated this data conforms to the equivalency of two foot contours and should satisfy most users who require this accuracy.

Qualitative Analysis

Overview

Mapping standards today address the quality of data by quantitative methods. If the data are tested and found to be within the desired accuracy standard, then the data is typically accepted. Now with the proliferation of LIDAR, new issues arise due to the vast amount of data. Unlike photogrammetry where point spacing can be eight meters or more, LIDAR point spacing for this project is two meters or less. The end result is that millions of elevation points are measured to a level of accuracy previously unseen for elevation technologies, and vegetated areas are measured that would be nearly impossible to survey by other means. The downside is that with millions of points, the data set is statistically bound to have some errors both in the measurement process and in the vegetation removal process.

As stated, quantitative analysis addresses the quality of the data based on absolute accuracy. This accuracy is directly tied to the comparison of the discreet measurement of the survey checkpoints and that of the interpolated value within the three closest LIDAR points that constitutes the vertices of a three-dimensional triangular face of the TIN. Therefore, the end result is that only a small sample of the LIDAR data is actually tested. However there is an increased level of confidence with LIDAR data due to the relative accuracy. This relative accuracy in turn is based on how well one LIDAR point "fits" in comparison to the next contiguous LIDAR measurement. Once the absolute and relative accuracy has been ascertained, the next stage is to address the cleanliness of the data for a bare-earth digital terrain model (DTM).

By using survey checkpoints to compare the data, the absolute accuracy is verified, but this also allows us to understand if the vegetation removal process was performed correctly. To reiterate the quantitative approach, if the LIDAR operated correctly in open terrain areas, then it most likely operated correctly in the vegetated areas also. This does not mean that the bare-earth was measured, but that the elevations surveyed are most likely accurate (including elevations of treetops, rooftops, etc.). In the event that the LIDAR pulse filtered through the vegetation and was able to measure the true surface (as well as measurements on the surrounding vegetation) then the level of accuracy of the vegetation removal process can be tested as a by-product.

To fully address the data for overall accuracy and quality, the level of cleanliness is paramount. Since there are currently no effective automated testing procedures to measure cleanliness, Dewberry employs a visualization process. This includes utilizing existing imagery (if available), creating pseudo image products such as hillshades and 3-dimensional modeling, and statistical spatial analysis. By creating multiple images and using overlay techniques, not only can potential errors be found, but we can also find where the data meets and exceeds expectations. This report will present representative examples where the LIDAR and post processing performed exceptionally well, as well as examples where improvements are recommended.

Phase II Qualitative Assessment

Based on the samples tested by Dewberry, it is our professional judgment that this data easily meets the desired accuracy for not only 2 ft contours but also for cleanliness suitable for most applications. Through this analysis, it became apparent that no gross blunders or major sensor malfunctions were detected. In fact, it was difficult to find significant errors. Any errors presented in this report should not affect the use of this data for most needs. It is Dewberry's intent to identify "issues" with the data so that further data collection and processing can be improved for the governing parties responsible for LIDAR data collection. This analysis will also address the quality of the data for additional verification purposes.

The data tiles were sampled in strategic locations to aid in identifying potential problems. Tiles were also chosen to correspond with the flight path blocks that the LIDAR provider utilized. This allowed Dewberry to test a multitude of data flown on different days. Additionally tiles were chosen to include areas of dense forest, swamps with mixed vegetation, agricultural, and urban terrain. Some tiles will illustrate duplicate issues. This is meant as a means to identify that these particular issues occur in more than one tile.

Tile AB132B2

Figure 7 illustrates a tile in 3D. This image is composed of a hillshade draped over a 2 meter grid with a vertical exaggeration of 5. By exaggerating the vertical components, potential artifacts stand out. This tile exhibits relatively clean data and no issues are present. Figure 8 illustrates a zoomed section of the tile focusing on a small stream. Figure 9 illustrates the cross section of the same stream channel which depicts the ability of LIDAR to measure channel geometry. The advantage of utilizing two meter LIDAR point spacing is the ability to detect smaller drainage patterns and their associated channel geometry. If this channel were more incised due to erosion and needed to be studied for floodplain mapping, it would be critical to measure the geometry to use for hydraulic modeling. The alternative would be the more expensive process of performing ground surveys. Figure 10 and Figure 11 illustrate the location of a cross section within a field to show the relative accuracy of the LIDAR. Here it can be seen that the elevation changes very little over a distance of 80 meters and that the relative accuracy looks strong.

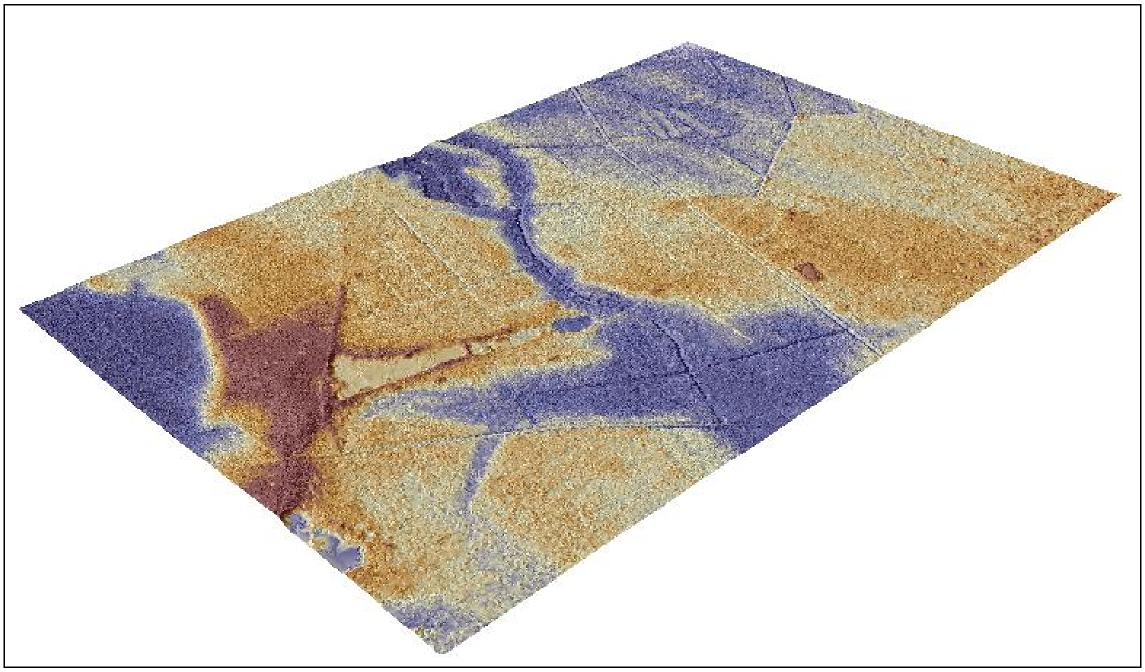

Figure 7 – An example of a TIN grid and hillshade with vertical exaggeration of 5 to aid in the detection of artifacts. This data exhibits no significant artifacts.

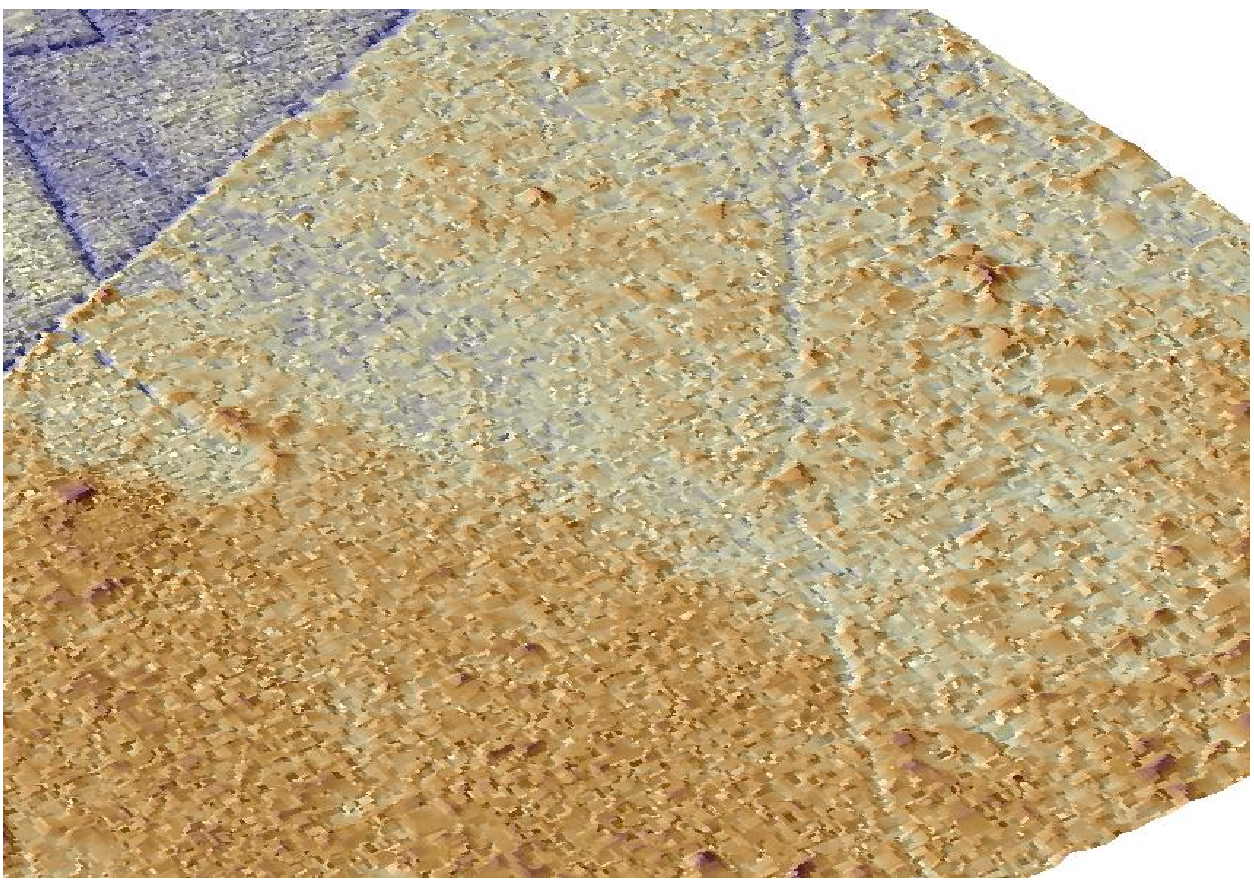

Figure 8 – Zoomed in to identify small streams for drainage analysis.

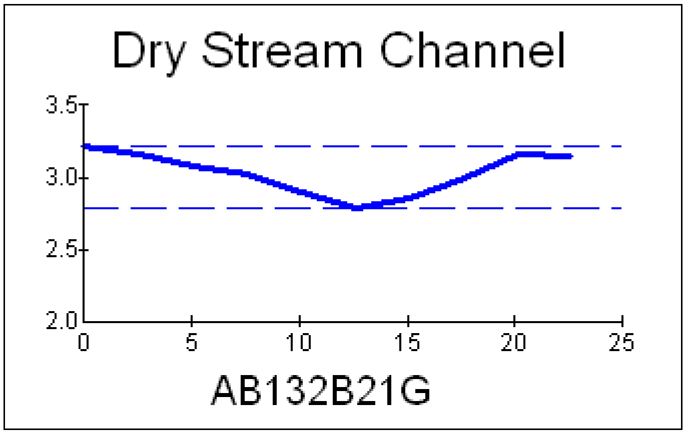

Figure 9 – Cross section of stream channel illustrating the ability of the LIDAR to measure channel definition. Topographic LIDAR does not measure below the water surface. All units are in meters.

Figure 10 – Location of cross section in middle of agricultural fallow field using the intensity image.

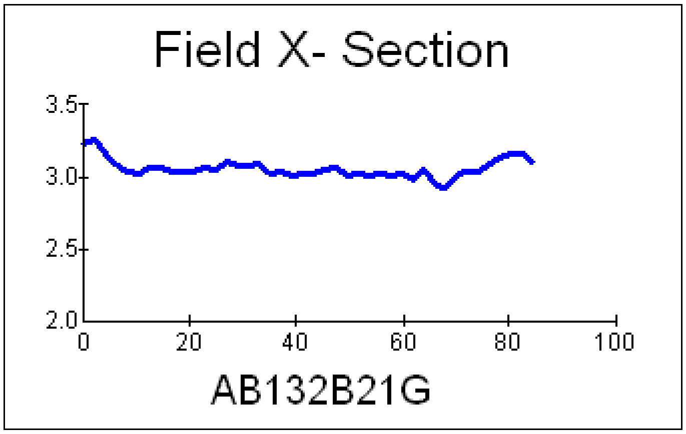

Figure 11 – Cross section of field. Note the relative accuracy and little change over a distance of 80 meters. All units are in meters

AB132B41

Figure 12 illustrates the location of a cross section in a heavily vegetated area. Figure 13 illustrates the bare-earth terrain cross section of the forest floor. Although it appears rough, the changes over short distances are approximately 15 cm. Over the entire distance the minimum and maximum variation is approximately 40 cm. The dotted blue line shows the best fit trend to the surface which again, shows that the changes in elevation are not drastic. It is easily conceivable that this amount of change exists within this forest type for this geographic location.

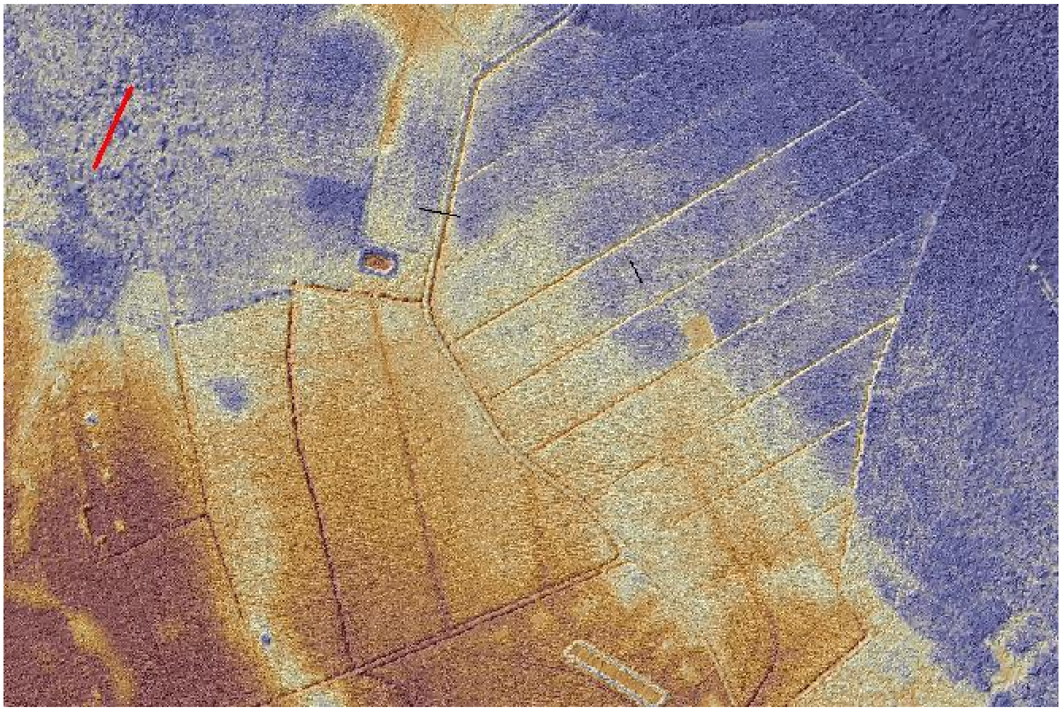

Figure 12 – Location of forest cross section.

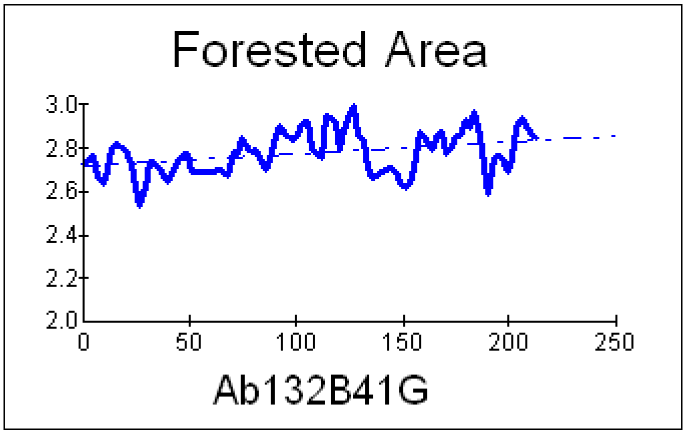

Figure 13 – Cross section of forest to illustrate the relative smoothness of the terrain for a heavily vegetated area. The dotted line illustrates the best fit trend of the surface. All units are in meters.

AB136B41

Figure 14 illustrates potential artifacts along the lower drainage area north of the highway. These artifacts are minimal, and the only limitation is to avoid cutting hydraulic cross sections at these exact locations.

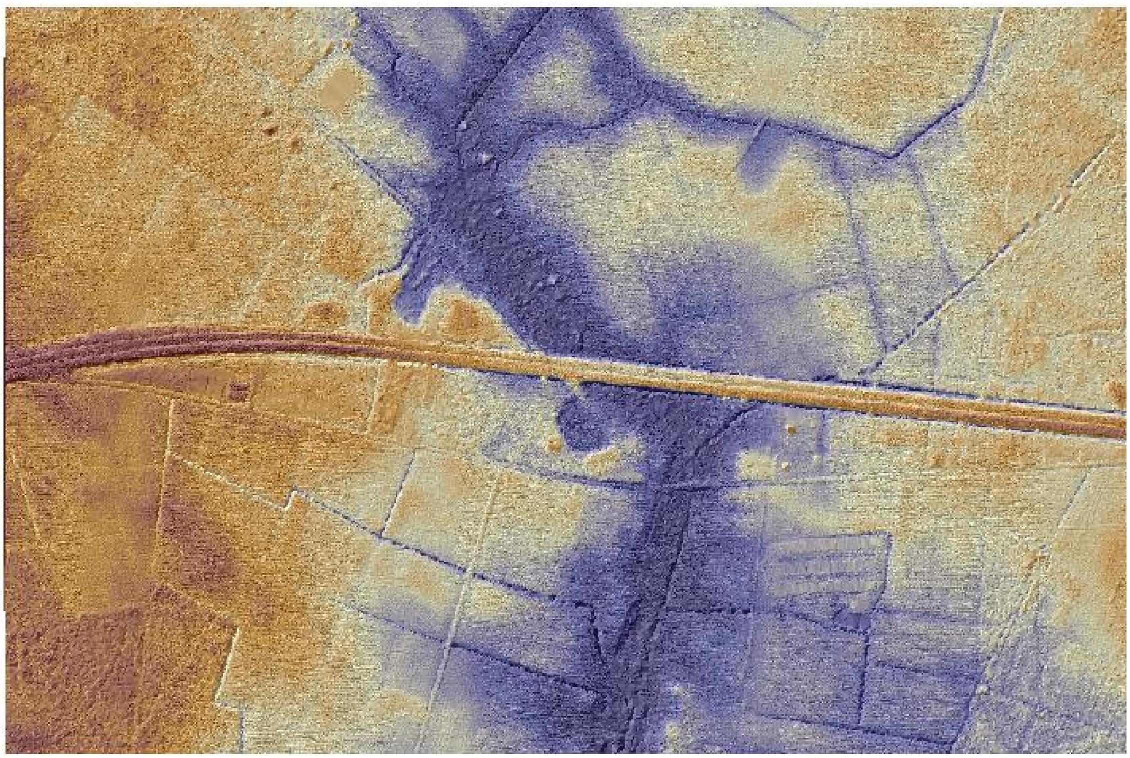

Figure 14 – Potential artifacts within lower drainage area (center, north of road).

AC130B2

Figure 15 depicts potential artifacts located in forest areas which are highlighted. Figure 16 is used to aid in correlating the area of potential artifacts with the intensity image and associated land cover type. These potential artifacts are not usually an issue as they are relatively small and do not impede the flow of water significantly. They appear to not have a large impact on the topography other than for that particular exact location. Another questionable area is the two berms on each side of the pond in the center of the image. Both these higher elevated areas appear close to tree lines which make them candidates for artifacts; but upon further examination, they seem to be legitimate based on the intensity image. This illustrates that not all small features that are elevated are artifacts.

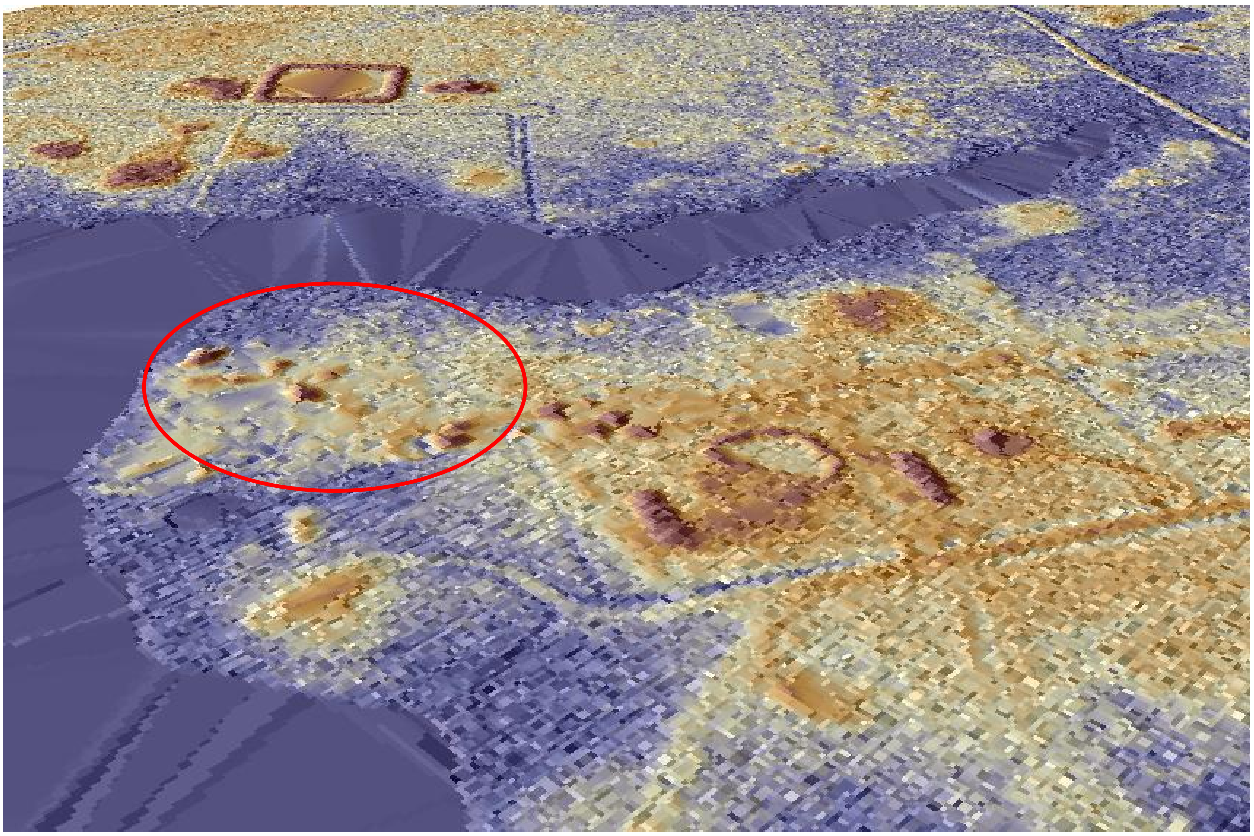

Figure 15 – Potential artifacts (darker brown) in areas of forest. Not all brown shades are artifacts such as the edges of the pond in the center of the image.

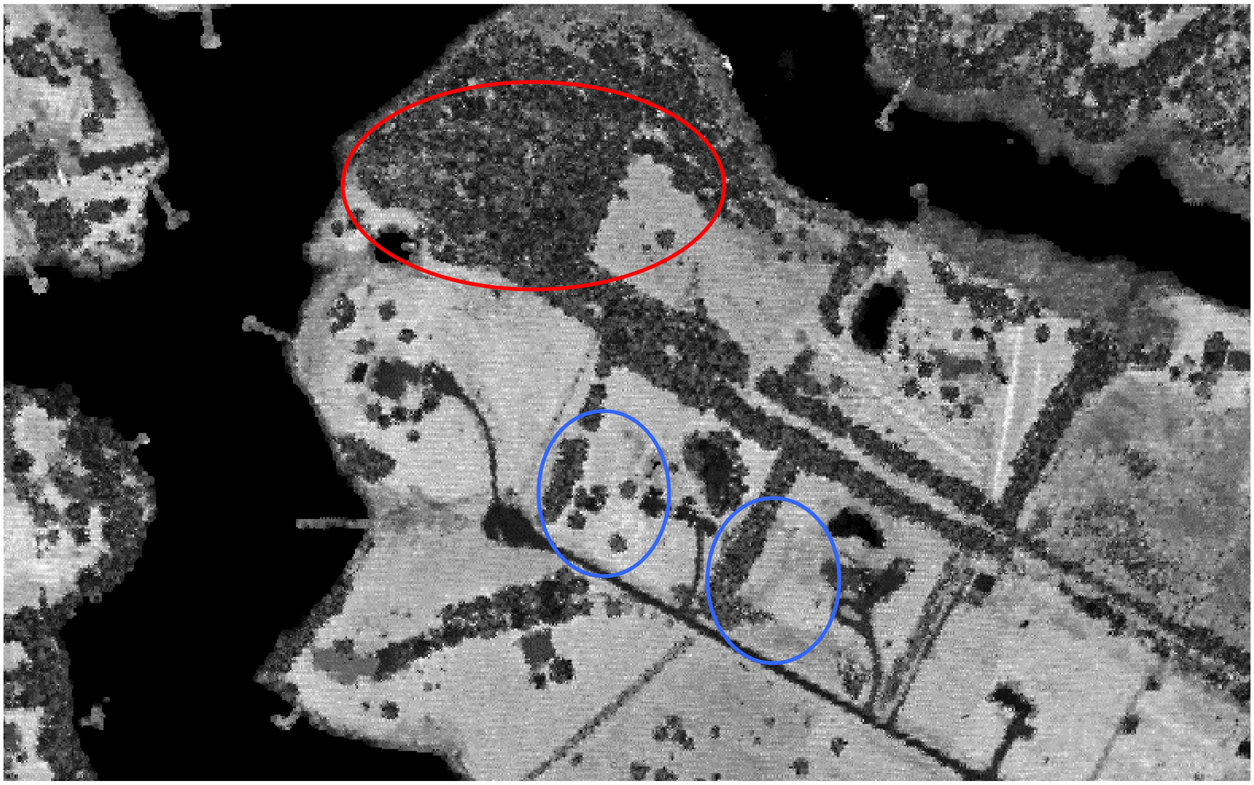

Figure 16 – Intensity image with the forest area that contains potential artifacts. Berm area in blue, notice the subtle change in the intensity image in the berm locations.

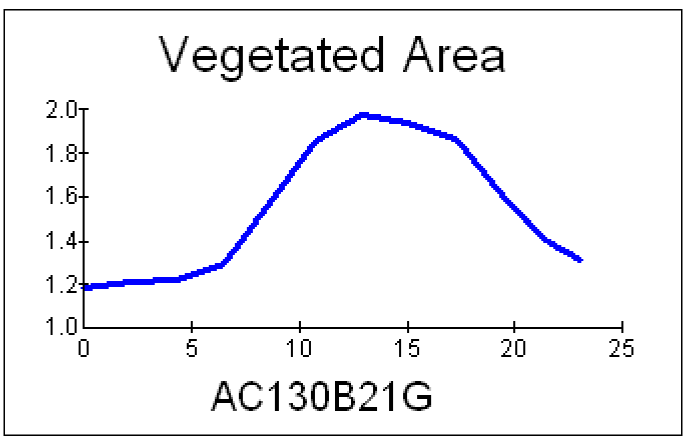

Figure 17 -Cross section of berm near vegetated tree line. All units are in meters.

AD137B6

Figure 18 and Figure 19 illustrate the location and related cross section encompassing the field drainage ditch and road. The road is elevated from the fields which is typical.

Figure 18 – Location of cross section of road and drainage ditches.

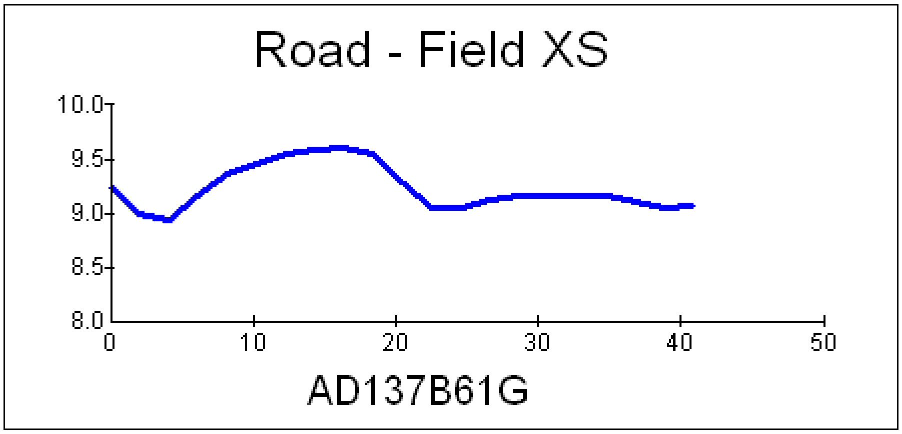

Figure 19 – Cross section of road and drainage ditch leading to fields. All units are in meters.

AE134B2

Figure 20 and Figure 21 illustrate the location and cross section of a road profile. The road profile was extracted from the TIN as this provides the most accurate surface model with minimal interpolation. Overall the profile is weak but still within the specifications of 2 ft contours. Typically profiles tend to be flatter and in other tested areas within this Phase II dataset, they are. Road profiles can yield weaker results due to the absorption of the LIDAR pulse which can cause a noisier level of accuracy and slightly lower elevations.

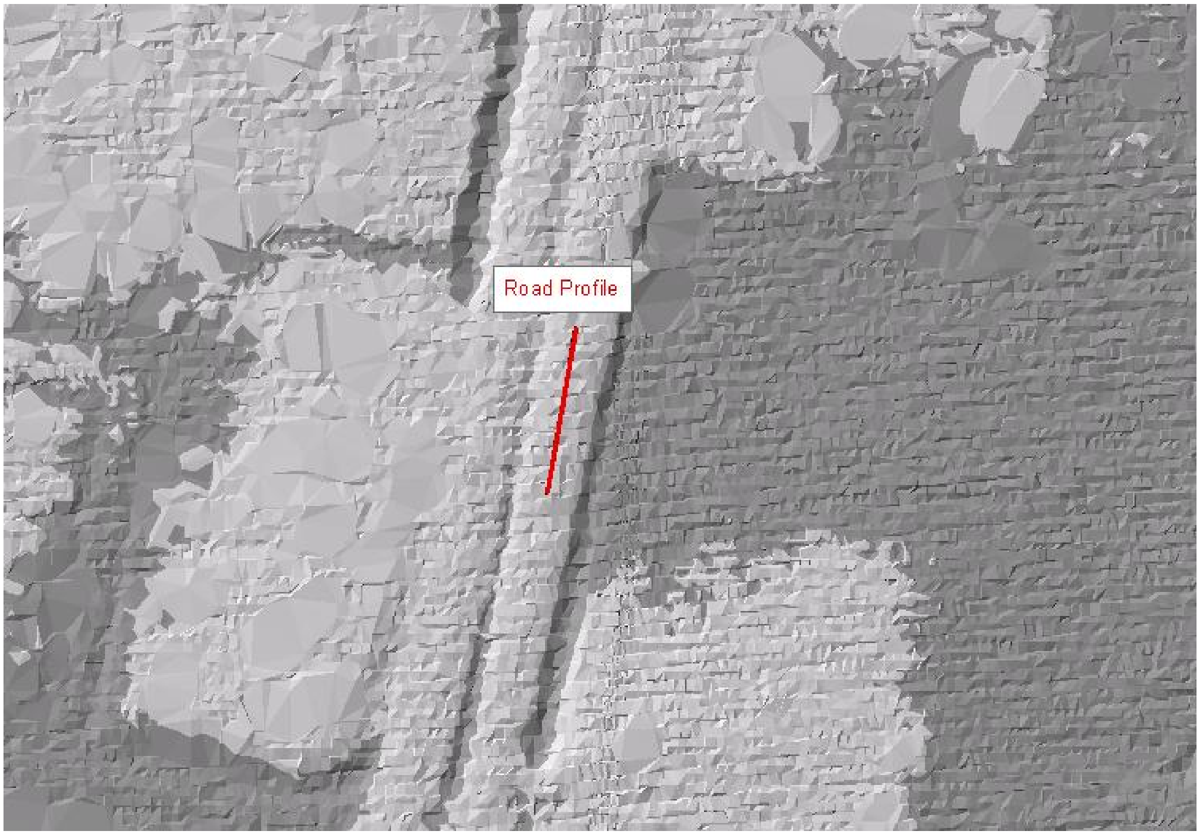

Figure 20 – Location of road profile with the TIN surface model it is extracted from.

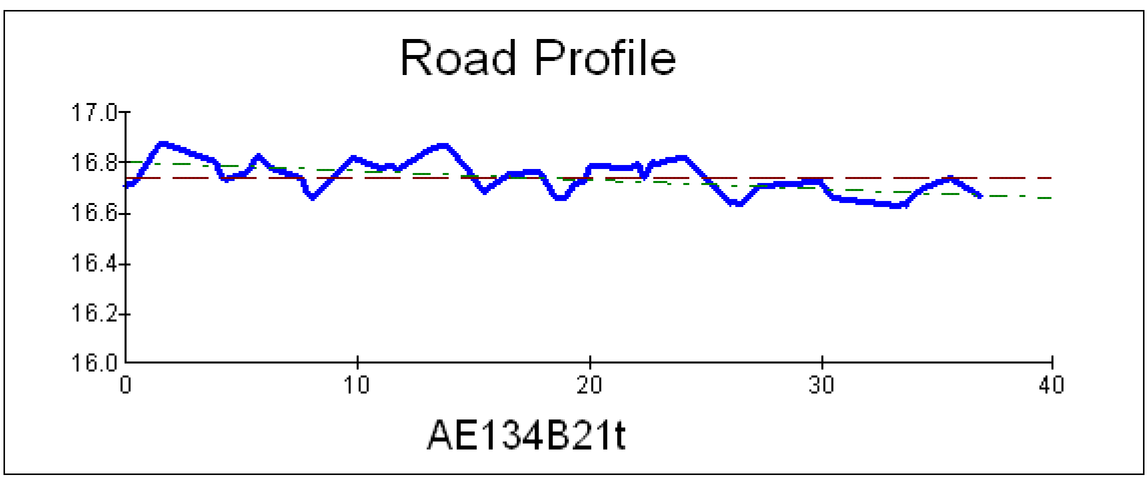

Figure 21 – Cross section of road profile. The green line is the best fit trend line and the red line is the average. Typically road profiles are slightly better but asphalt, and especially newer asphalt, can absorb the LIDAR at different rates can cause the elevations to undulate and be slightly lower (few centimeters). All units are in meters.

AG135B1

Figure 22 and Figure 23 illustrate potential artifacts. The TIN triangles in these areas are larger because elevated points were filtered out and there are fewer remaining LIDAR points that penetrated the dense vegetation to the forest floor in these areas.

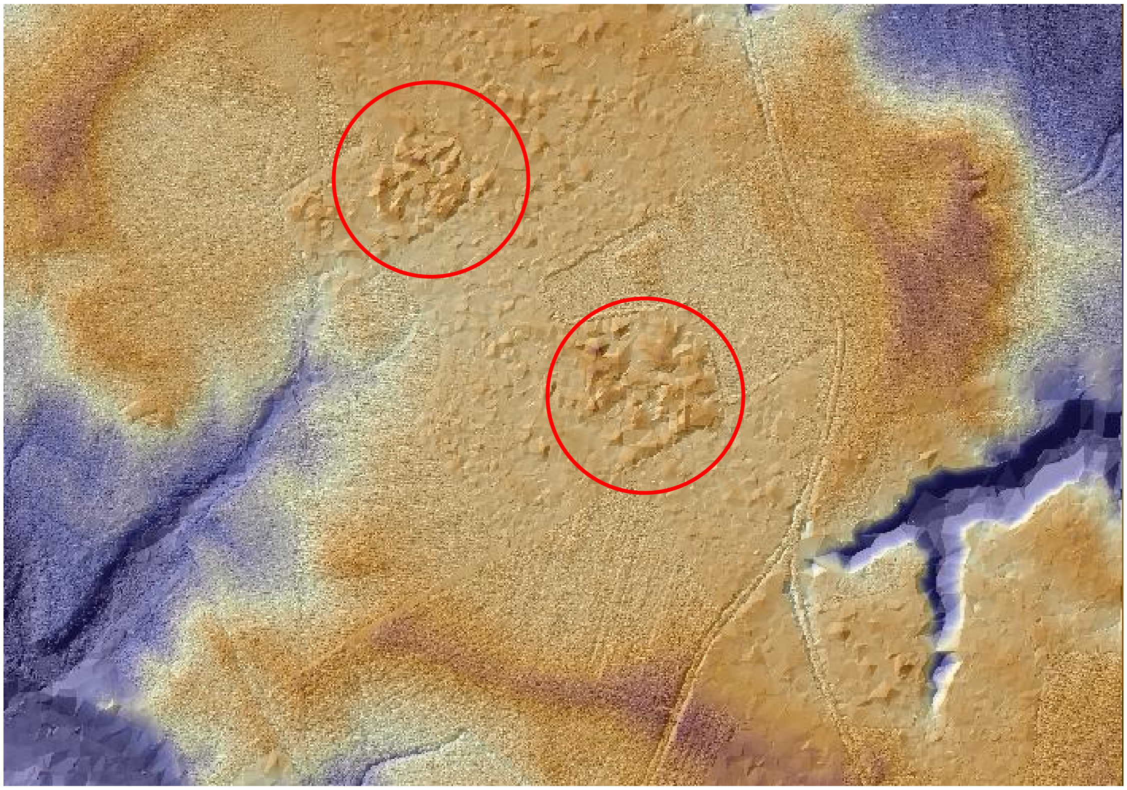

Figure 22 – Potential artifacts highlighted with red circles. See Figure 23.

Figure 23 – Areas of potential artifacts located within forested area.

AH1346B5

Figure 24 illustrates potential artifacts along the highway embankment. This area consists of tall trees. These artifacts could be cleaned better with manual editing which is more expensive. Figure 25 and Figure 26 depict the use of excellent algorithms for removing artifacts. In this area there is not only a road with culverts, but directly to the north of the culverts is a section of land that is in essence a "land bridge" or dam. Some algorithms would remove this land area due to its proximity to the road and the changing elevations. This clearly shows the true topography of the area.

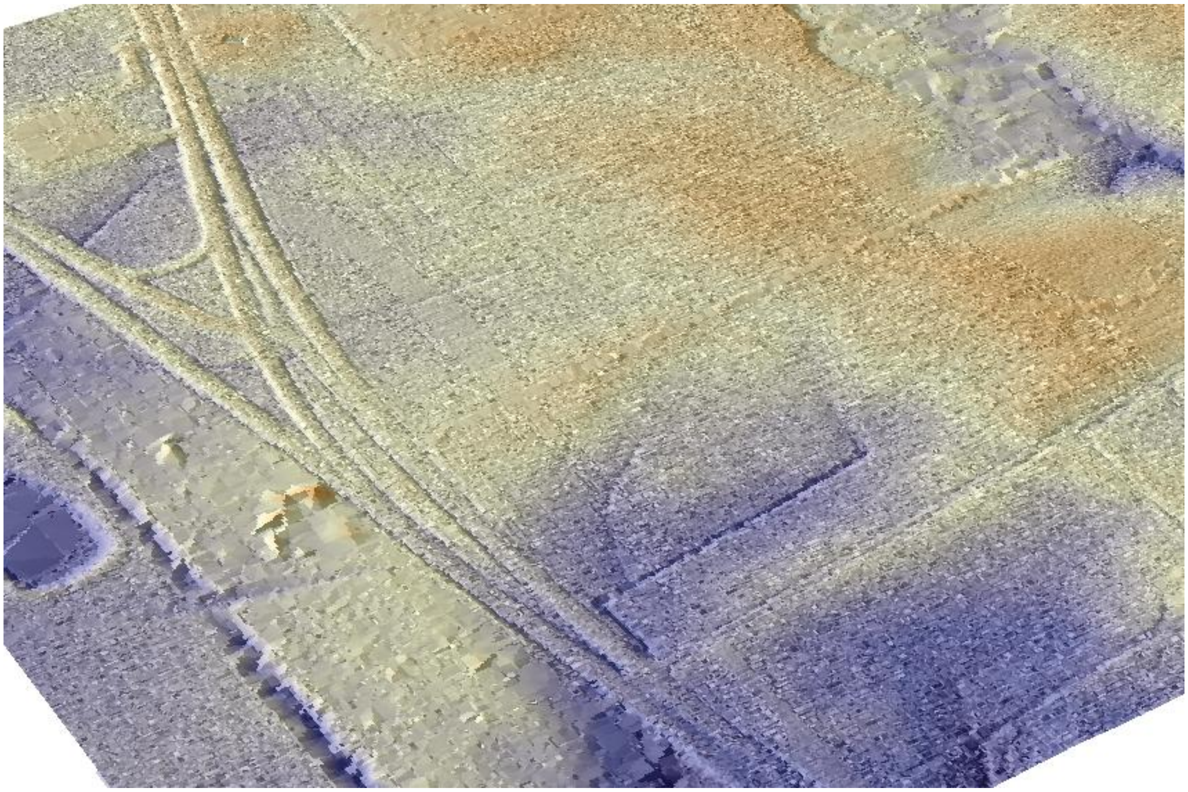

Figure 24 – Potential artifacts along highway embankment.

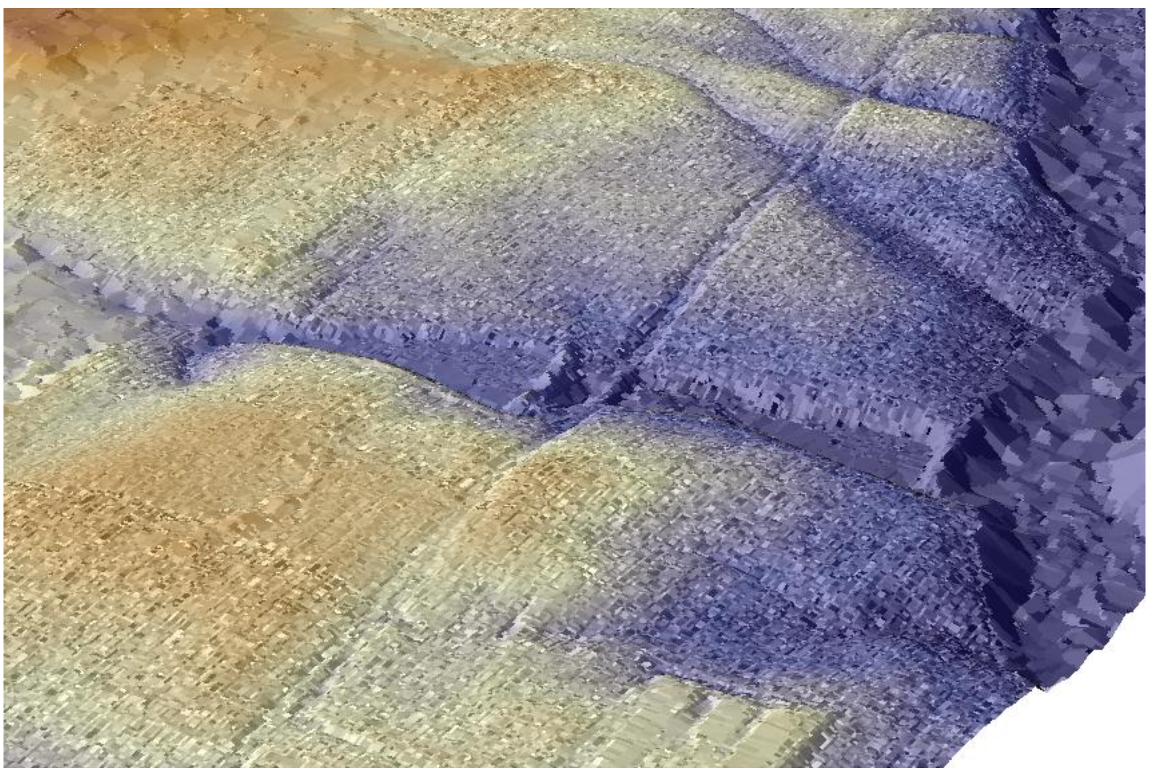

Figure 25 – Illustrates excellent artifact removal at the culverts and "land bridge" area (see Figure 26 for reference).

Figure 26 – Intensity image of culverts and "land bridge" or dam. Notice the topography north of the road based on the intensity image and that of the correlating elevations from Figure 25.

AI130B4

Figure 27 illustrate a potential artifact. Although the artifact removal process removed the structures efficiently for the surrounding area, one feature stands out. This figure highlights the LIDAR points color-coded by elevation overlaid on the intensity image. Figure 28 illustrates the cross section of the potential artifact. What should be noted here is the success rate of removing structures on the whole of the data set as opposed to a few structure artifacts that are left within the dataset.

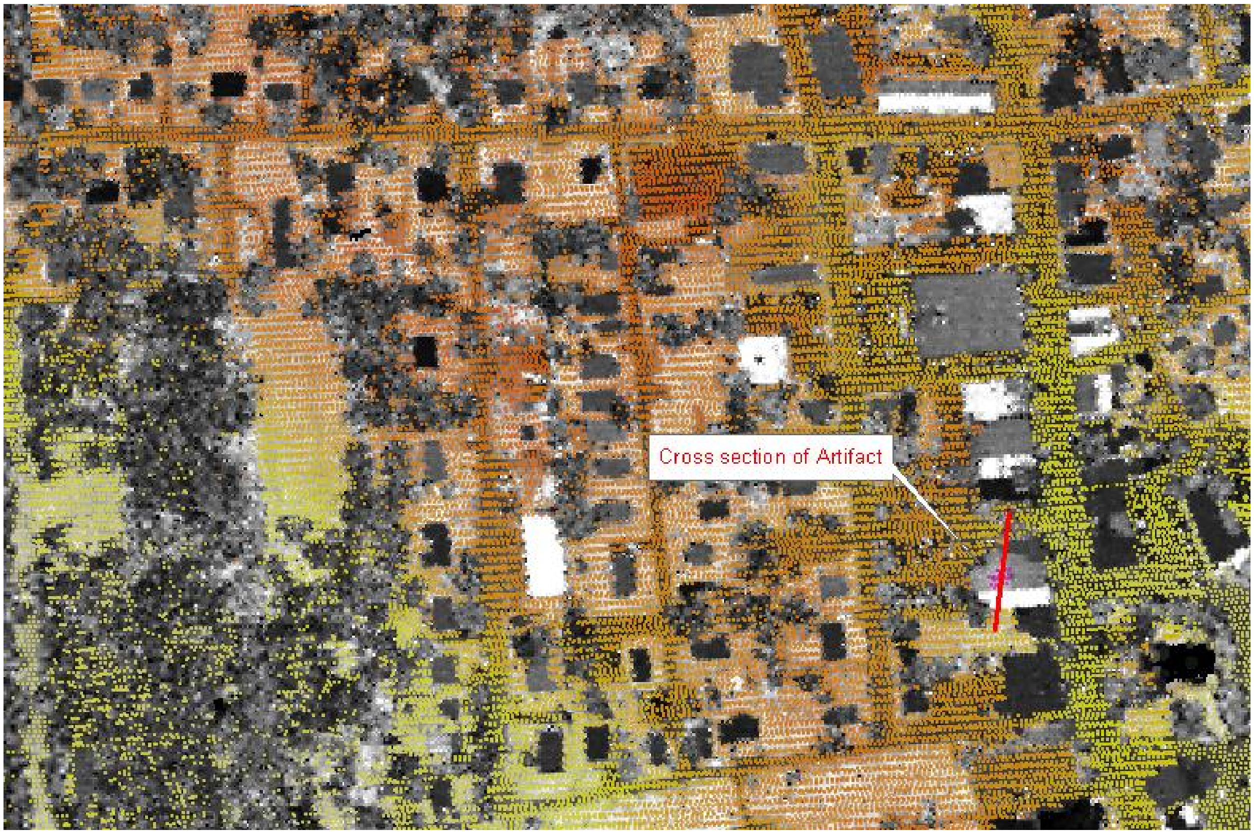

Figure 27 – Potential artifacts in urban environment. The above image depicts the LIDAR points and the location of the cross section (see Figure 28)

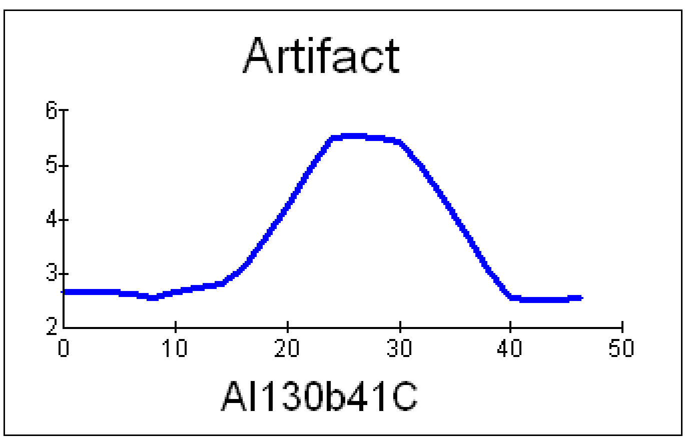

Figure 28 – Cross section of potential artifact. All units are in meters.

AL127B2

Although the intensity images are not part of the contracted QA/QC analysis, they have proved to be an invaluable resource as a tool to aid in Dewberry's analysis of the LIDAR elevations. These images convey additional information beyond a pseudo picture. Since they measure the amount of energy returning to the sensor, it allows us to measure the texture of the terrain. By utilizing this texture, we are able to ascertain some of the land cover categories and the level of confidence we have in their corresponding elevations. Currently the industry is researching ways to utilize these images to their full potential, but at this time there are not definitive tool sets to accomplish this automatically. Corrections are needed to normalize images between flight lines and between images, to apply radiometric corrections, and to perform tonal balance. The users must be aware that this is not a true photographic image and is not meant to replicate photography but that it is an excellent source of information to use in conjunction with the elevation data. Figure 29 illustrates the original intensity image which is dark and hard to see. Also two different flight lines can be seen on the right side of the image with one being much brighter than the other. This illustrates some of the issues with measuring the amount of returning energy at different times of day and with changing flying heights. Flying the same area with any of these changes can yield different intensity values. Figure 30 illustrates a custom histogram to help balance the image to be more usable. The result can be seen in Figure 31. In order to correct for the two flight lines, the source data would have to be manipulated before the image is created.

Figure 29 – Original intensity image with histogram stretch. This image also illustrates the two different flight lines on the right side of the image with different range of intensity values.

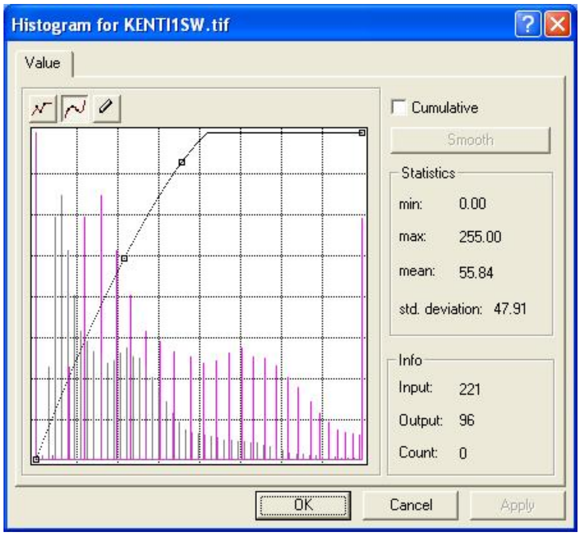

Figure 30 – Custom Histogram to achieve better tonal values.

Figure 31 – Intensity image after histogram manipulation. The image is now easier to see but still contains the two different flight lines on the right side of image.

Queen_NE_NW Intensity Image

Figure 32 illustrates unexplainable intensity data voids.

Figure 32 – Intensity data voids.

AN127B2

Figure 33 illustrates potential artifacts in the forested areas. These are minimal. Figure 34 and Figure 35 illustrate a problem that occurs a few times within this project in which there is a mismatch between scan lines. These differences between the scan lines can be caused by two main problems.

1. The absolute position of the sensor can have error. There are many factors that could cause this from the GPS position of the aircraft to tropospheric and atmospheric conditions.
2. A mis-calibrated sensor particularly in the scale factor applied to the scan lines.

Intensity data voids

The dynamics of LIDAR scan lines tend to "pull" th[illegible]es up which is commonly known as a "smile face". This is a known measurable factor and is accounted for with calibrations. However even with routine calibrations, some sensors can respond differently from one day to the next. In this tile, the ends of the scan line are pulled up slightly. Figure 36 illustrates the end of the zigzag pattern and the adjoining scan line. The elevations are color coded by elevation and it is obvious to Dewberry that the two scan lines exhibits different elevations for relatively the same area. Since there is a discrepancy in elevations, the vegetation removal process removes some points along the edge of one of the scan lines and in this case, the line on the left. This will then appear as a small ridge. Figure 37 is a cross section of the area in question. Over a short distance of 2 meters the heights change by 20 cm. This is not a large amount but does indicate that there is problem with this scan line.

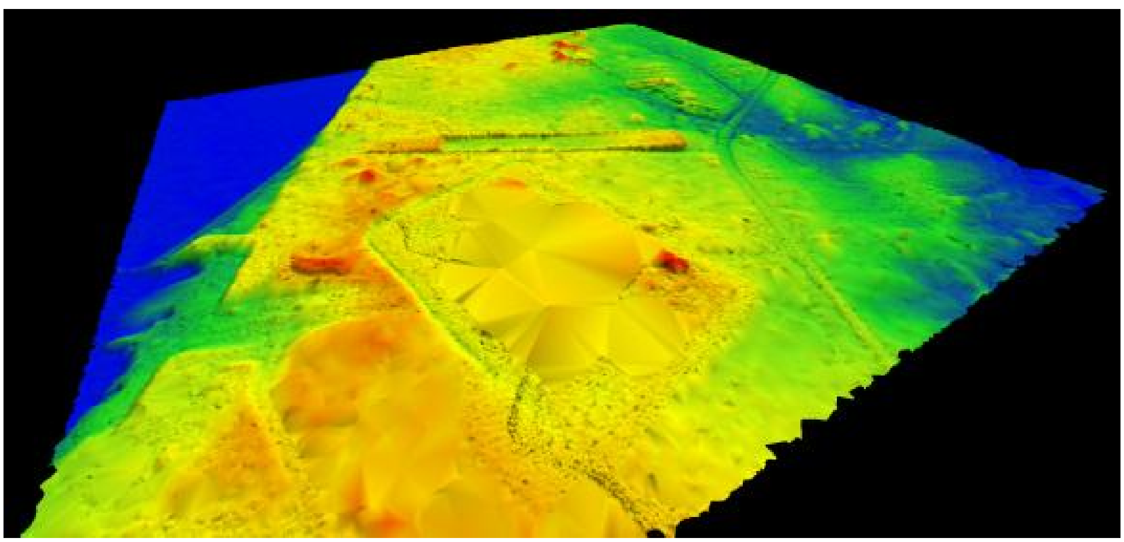

Figure 33 – Potential artifacts. Vertical exaggeration is 3.

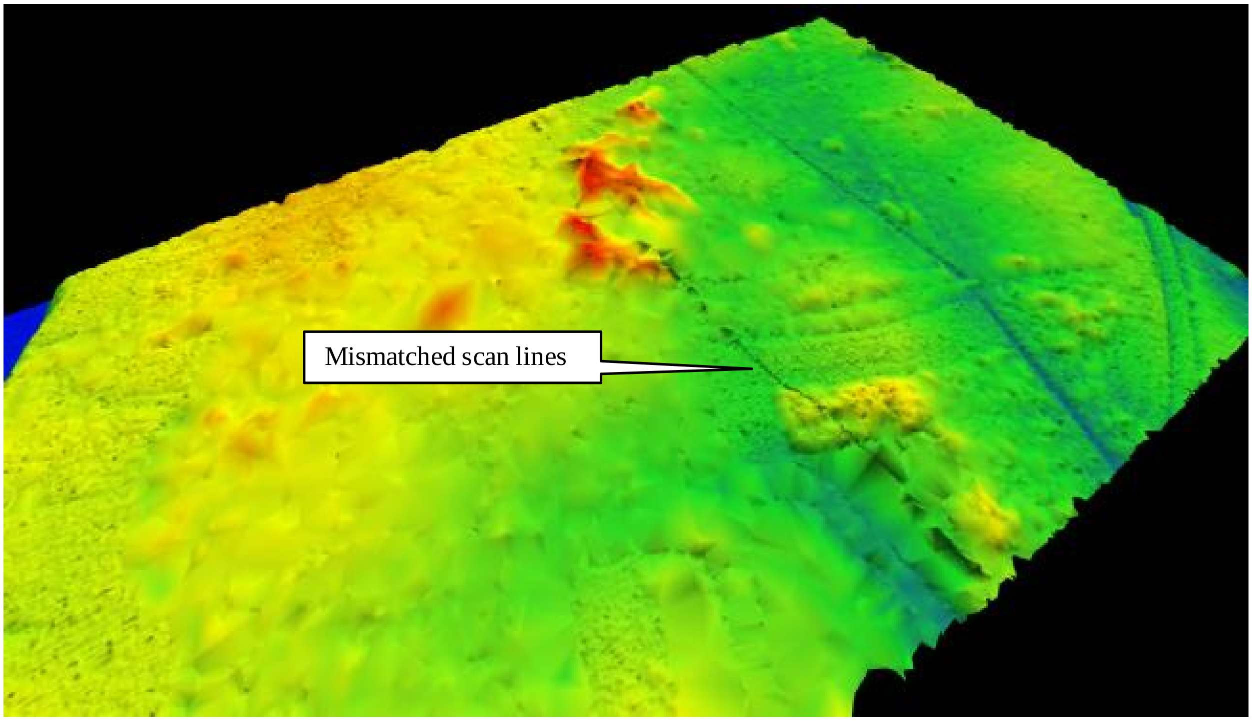

Figure 34 – Potential artifacts and mismatch between scan lines. Vertical exaggeration is 3.

Figure 35 – Area of mismatch between scan lines and area of artifacts.

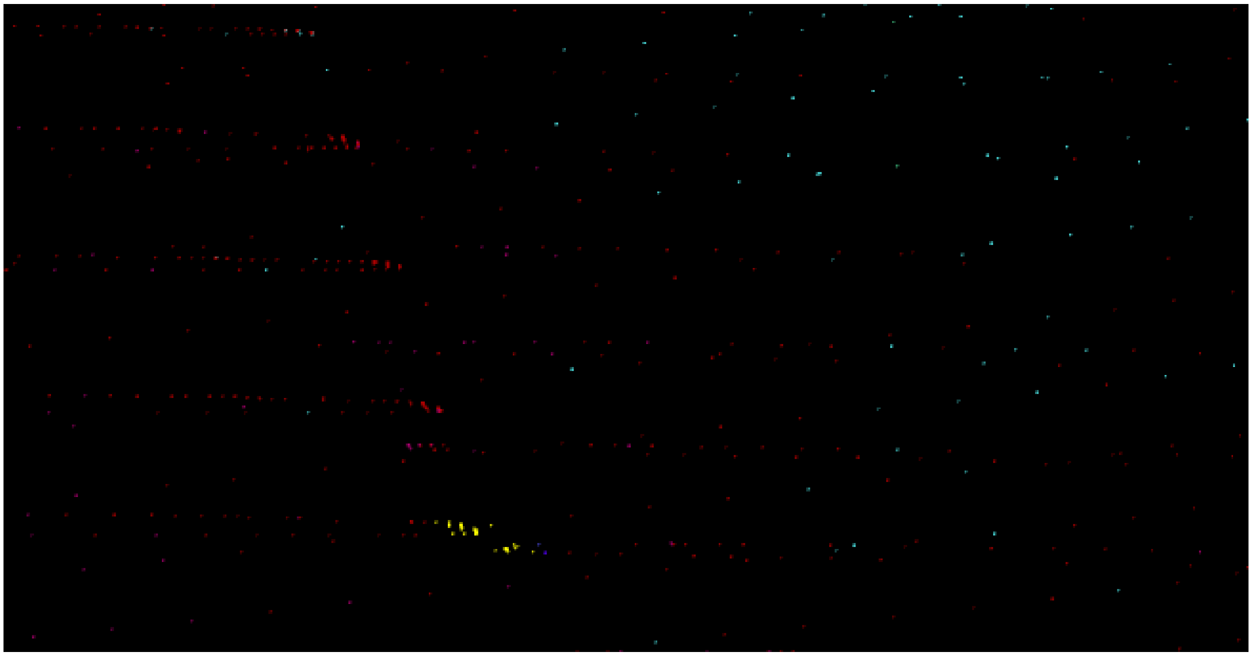

Figure 36 – Zoomed in view of scan mismatch. The end of the zigzag pattern of the scanner (red and yellow) can be seen in the center left of image with the adjoining scan line mostly in blue/grey.

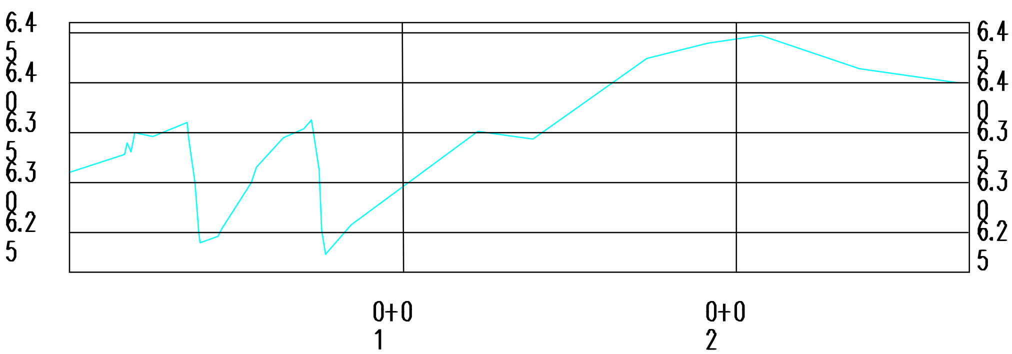

Figure 37 – Cross section at the join of end of the zigzag pattern seen in Figure 36. All units are in meters.

AO129B3

Using a vertical exaggeration of 3, Figure 38 appears to have artifacts. However upon closer inspection it can be seen that there are three scan lines in which two overlap on the left and right side of the image. The center area only contains one scan line with no overlap. As outlined in tile AN127B2, the differences between mismatched scan lines can cause elevation changes within the overlap area. In this overlap area, the data appears to have a higher level of noise factor where the relative elevations between LIDAR points of overlapping lines is higher than the relative values between LIDAR points of the same scan line. Figure 39 illustrates the same image with a vertical exaggeration of 1. This shows that the differences are not very large.

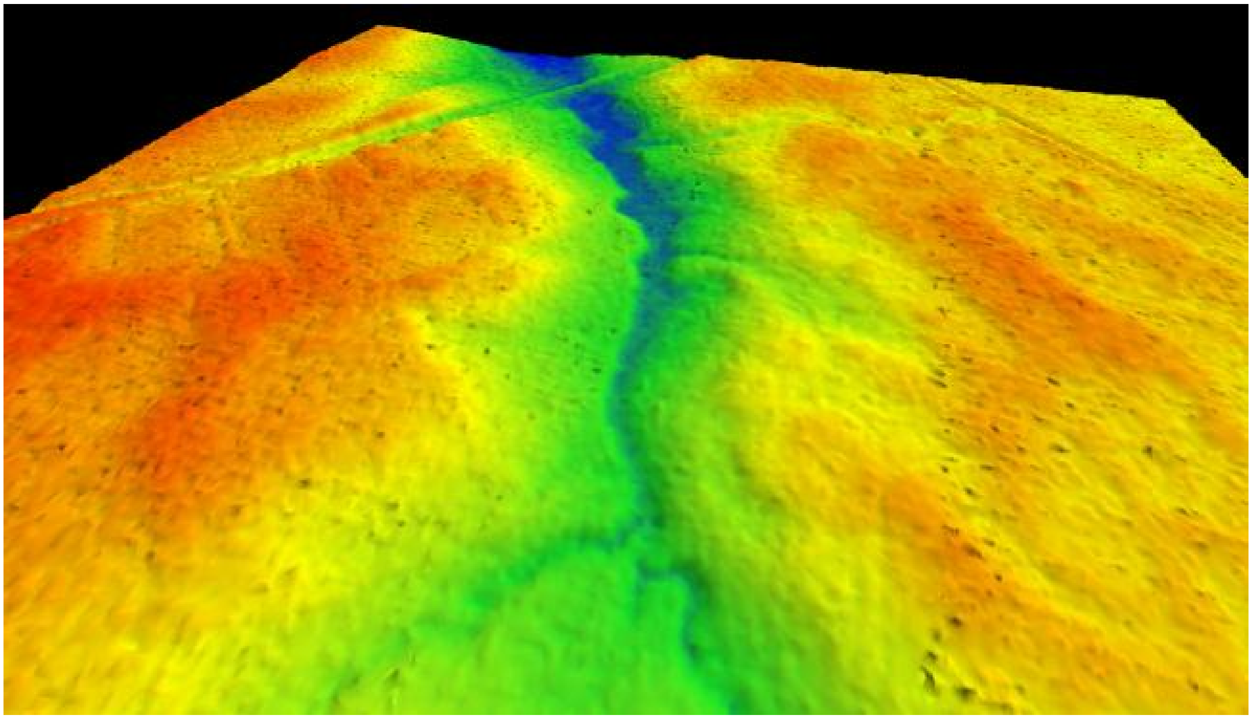

Figure 38 – Potential pseudo artifacts caused by differences between scan lines. Vertical exaggeration is 3.

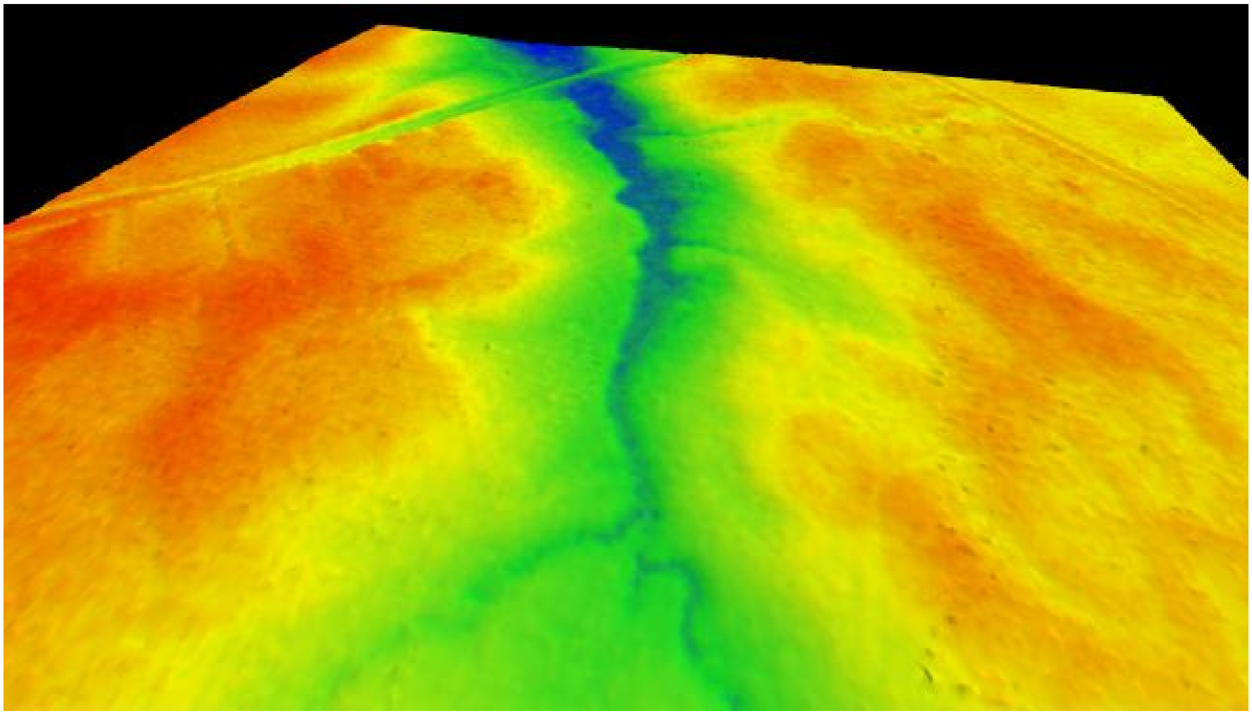

Figure 39 - Potential pseudo artifacts caused by differences between scan lines. Vertical exaggeration is 1.

Figure 40 illustrates a cross section of a stream within the LIDAR points color coded by elevation. Also the edges of the scan lines as outlined above are evident on each side. Although there is a slight mismatch Figure 41 clearly shows that the stream channel definition is easily seen and measured. The mismatch between these flight lines appears to be in the 0 -10 cm range.

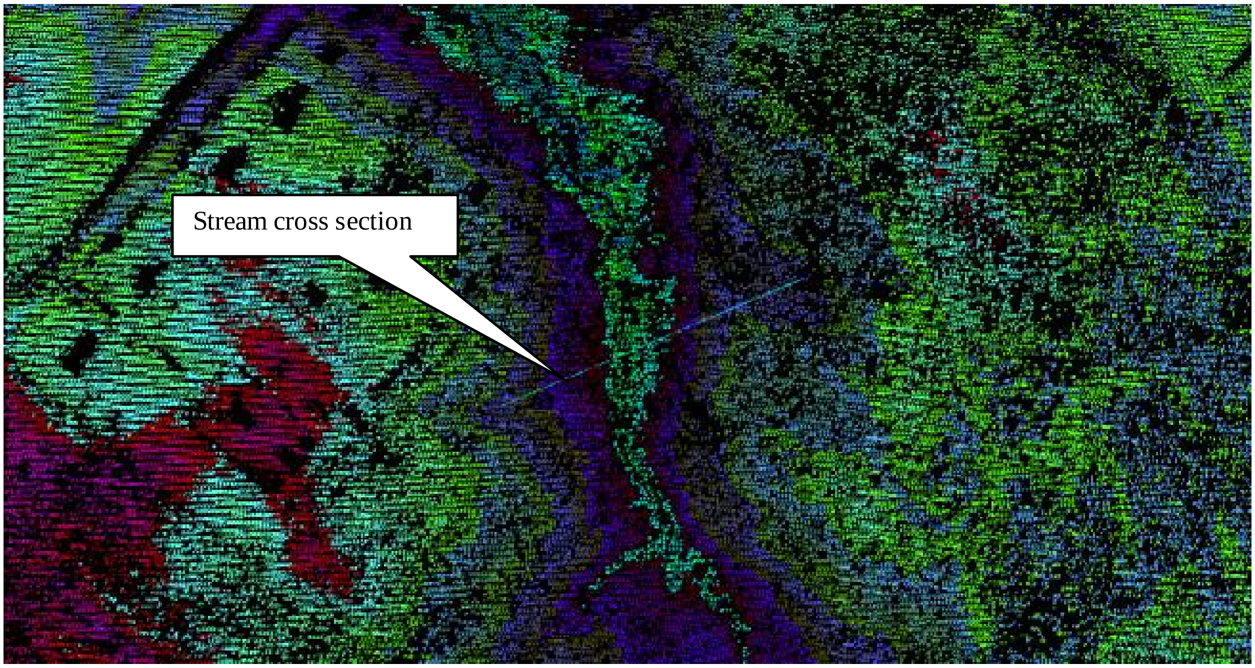

Figure 40 – Location of cross section relative to the LIDAR points color coded by elevation to test for channel definition.

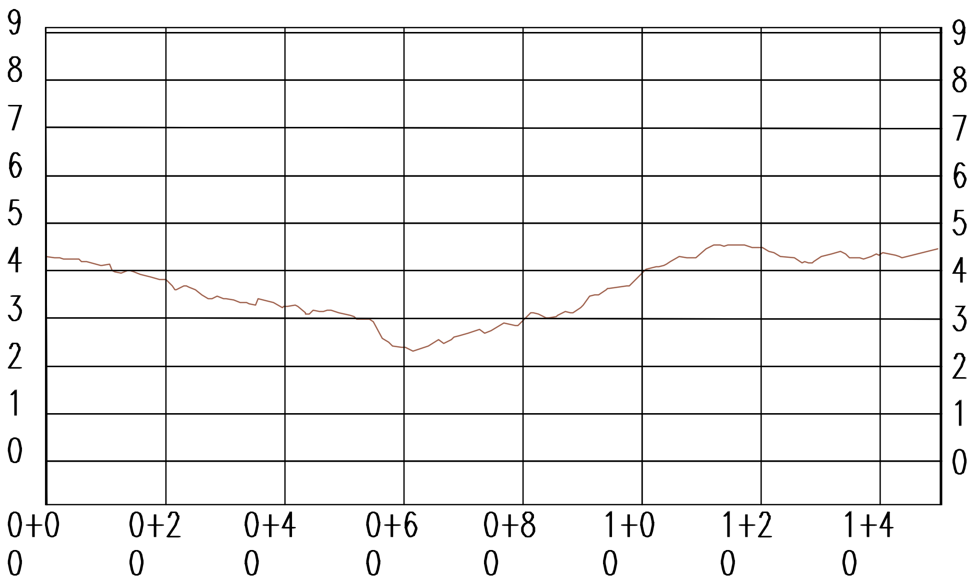

Figure 41 – Cross section of stream illustrating relatively good channel definition measurements. All units are in meters

A0131B6

Figure 42 illustrates the attention to detail for editing buildings to create a bare-earth surface model. In the center of the tile, the points which were part of the building were removed. However there is a courtyard and the points remain for this area. Most editing procedures remove all points when buildings are filtered out. Figure 43 again illustrates the differences at edges of scan lines in areas of overlap and non-overlap. Figure 44 is a zoomed in 3D view of the scan line edge issues.

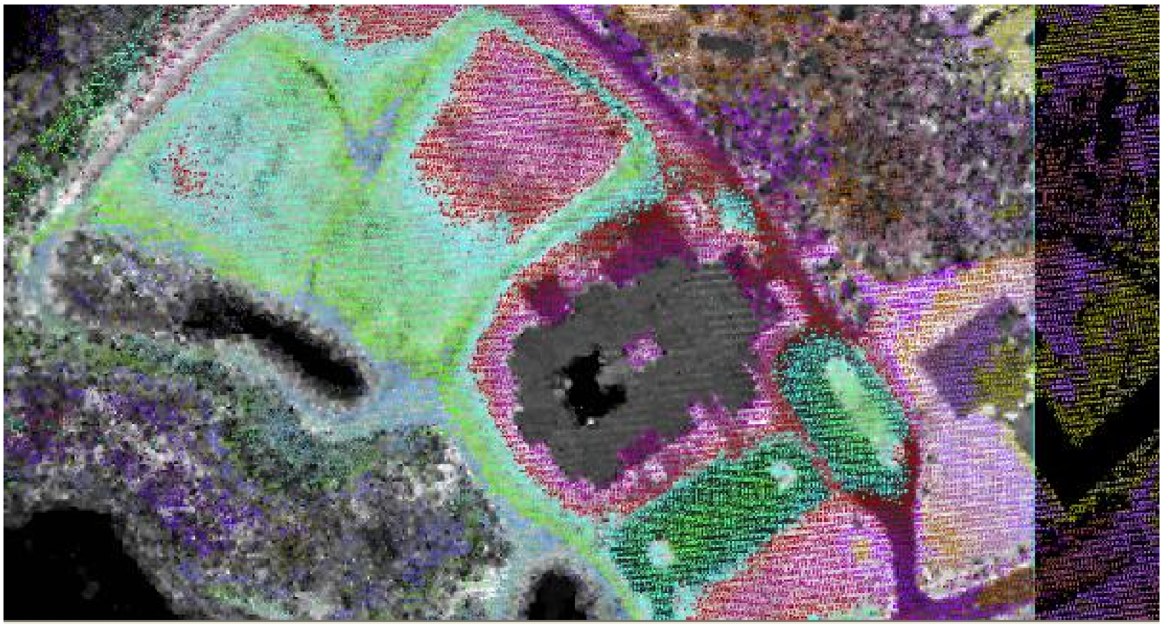

Figure 42 – This illustrates the attention to detail for creating a bare earth surface model. Here LIDAR points, color coded by elevation are overlaid on the intensity imagery for reference.

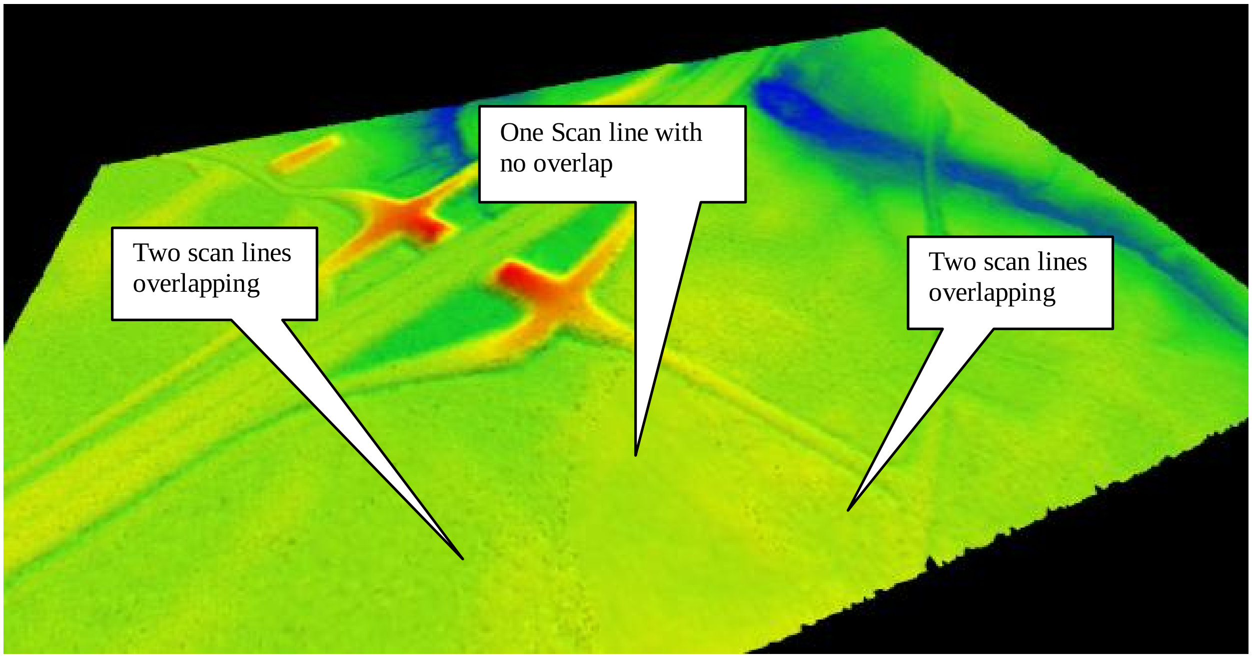

Figure 43 – Illustrates the issues with overlapping flight lines and the inherent noise level of accuracy.

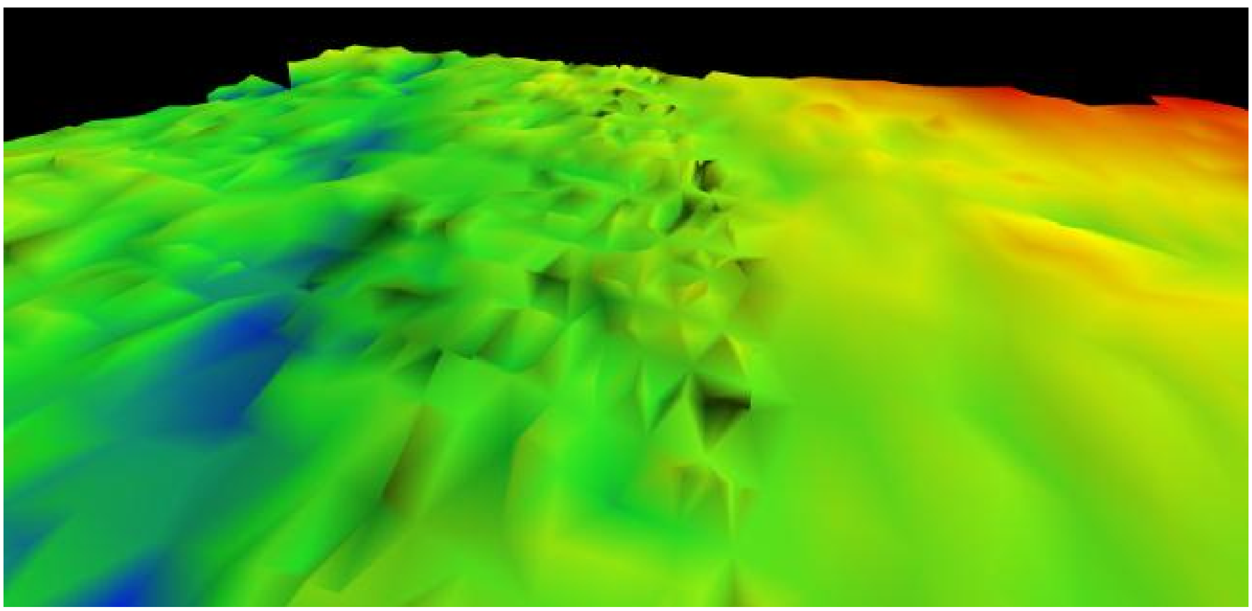

Figure 44 – Area of overlap between two lines on the left and one line on the right. The difference is approximately 10 cm.

M144B5

Figure 45 shows the location of a cross section between a forested area and an agricultural field. The aim was to make sure that the elevation of the field was relatively close to that of the forest and that no crops were growing to influence the elevations. Figure 46 clearly shows what would typically be predicted, the forest slightly higher with the under-story, the field plowed for many years fairly flat and slightly lower that the forest, and a drainage ditch at the edge of the field.

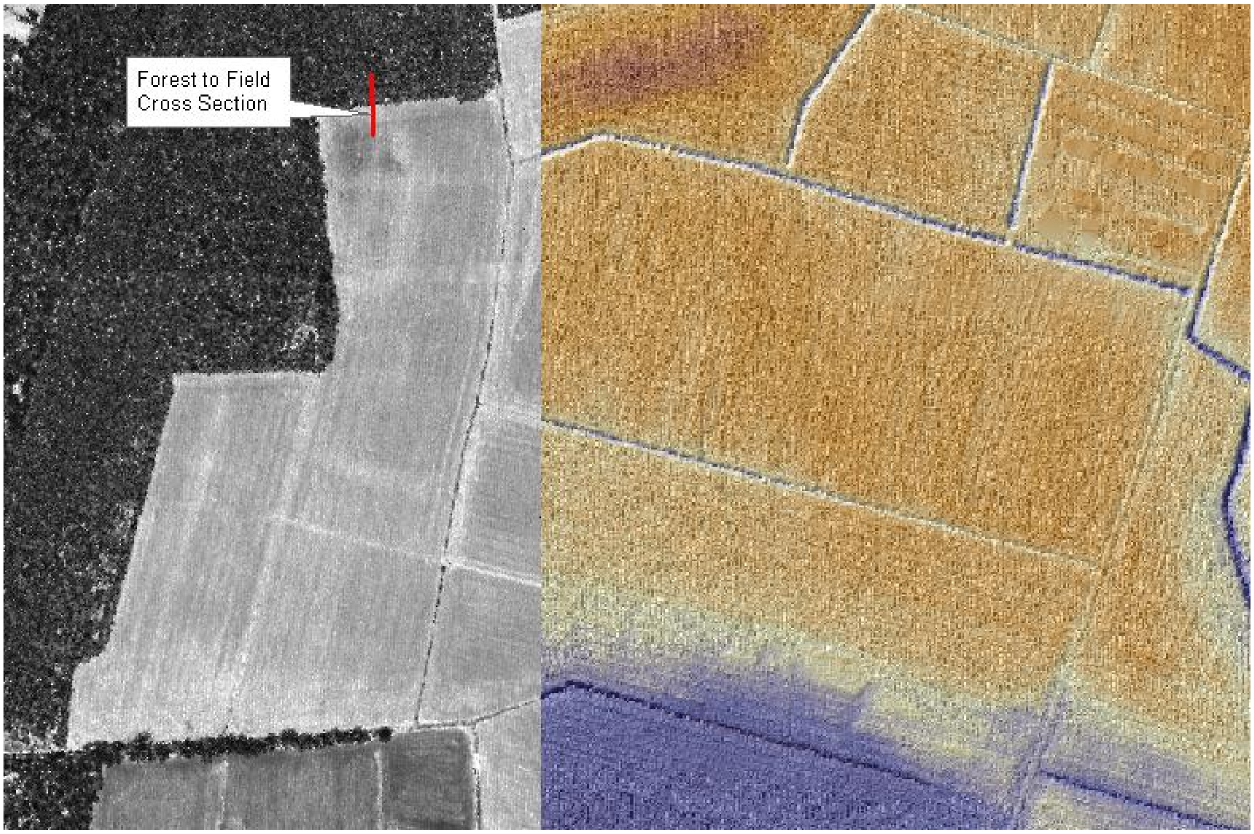

Figure 45 – Cross section between forest and field to illustrate relative elevations. The intensity image is on the left and a combination of a hillshade with a TIN grid on the right.

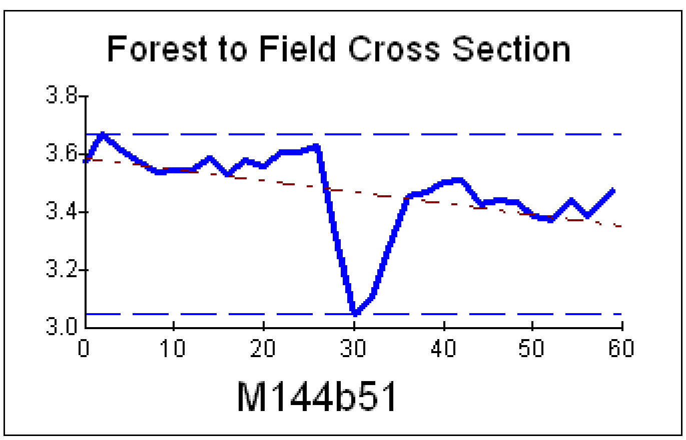

Figure 46 – Cross section of forest to field with drainage ditch on the fields edge.

N143B2

Figure 47 illustrates excellent point density of the forested area and agricultural fields.

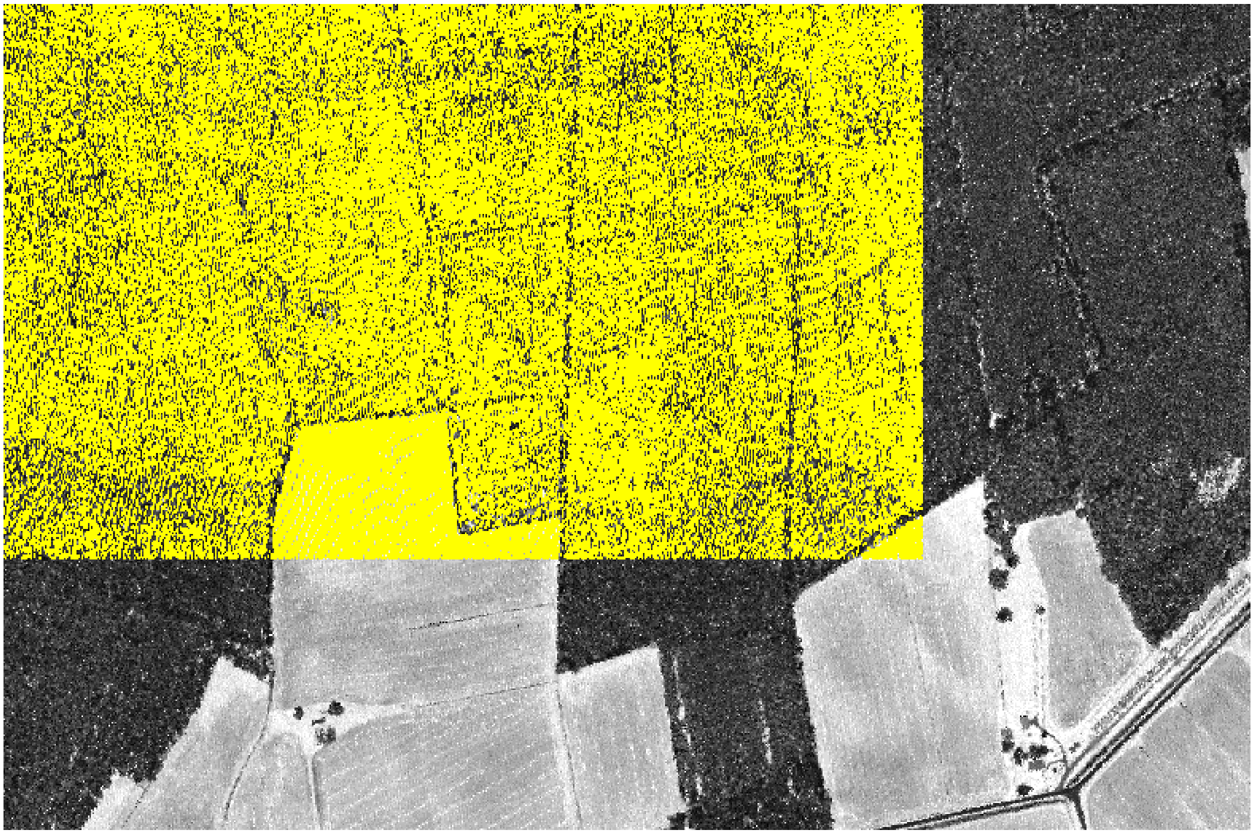

Figure 47 – Point density of forested area and agricultural fields.

Q143B2

Leaving bridges or editing out bridges has been debated within the industry. Some transportation people like to leave then in while hydrologic and hydraulic engineers prefer to have them removed. Both have good arguments. Figure 48 shows inconsistency within one tile. For the bridge on the left, the elevated sections have been removed. The bridge on the right has a mixture which contains some of the structure and some of the structure removed. This is not indicative of what the Phase II dataset contains. Overall most bridges are very consistent whereby they are left in except for the higher structures. The advanced algorithms did not remove these important features if they were close to ground surfaces.

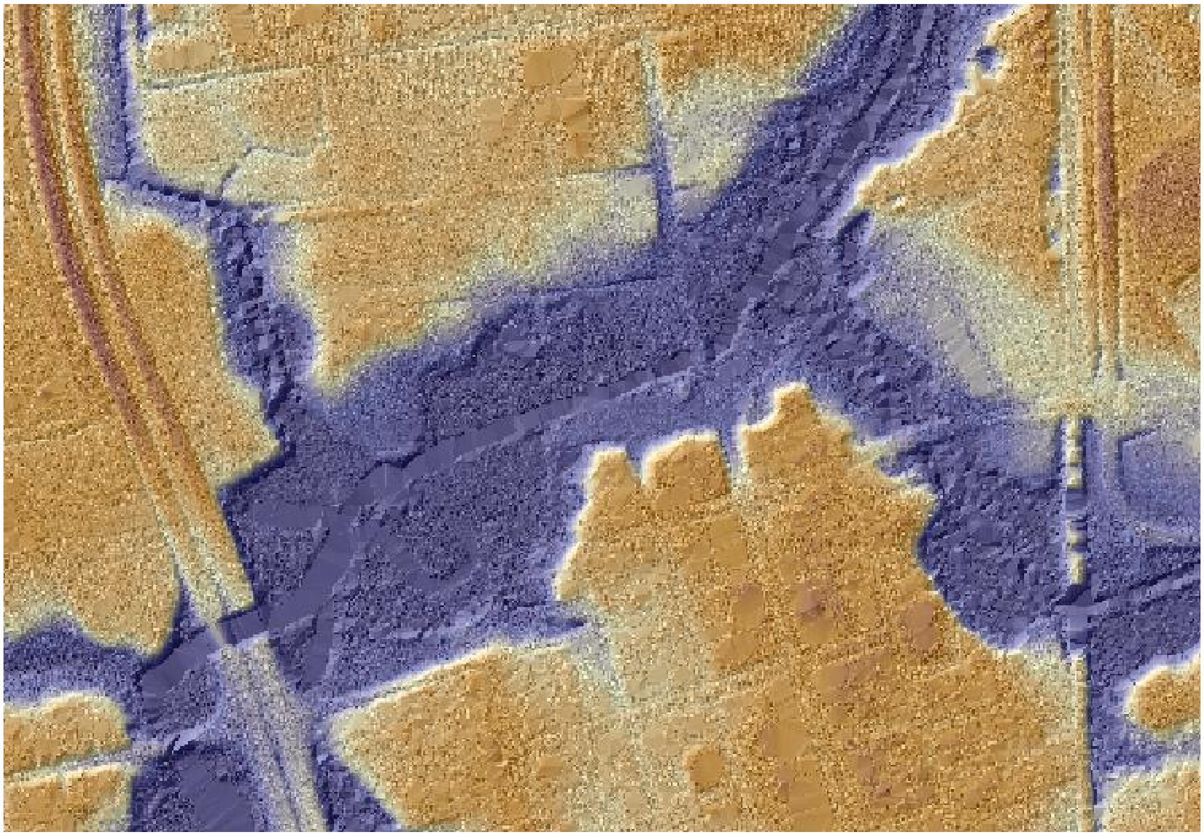

Figure 48- Inconsistent bridge editing. The bridge on the left has been removed where as the bridge on the right is partly removed.

Z129B6

Figure 49 reiterates the issue of the differences between scan lines that overlap and scan lines that do not. Figure 50 depicts three scan lines where two overlap on each side with the center not having any overlap. Since the grouping of points at the end of the scan lines can have inherent error due to the velocity changes of the whisk broom scanner, controls are entered during processing to eliminate some of these points. With this data the parameter set to exclude these points was not set large enough. Figure 51 illustrates a 3D view of the scan line edge issue.

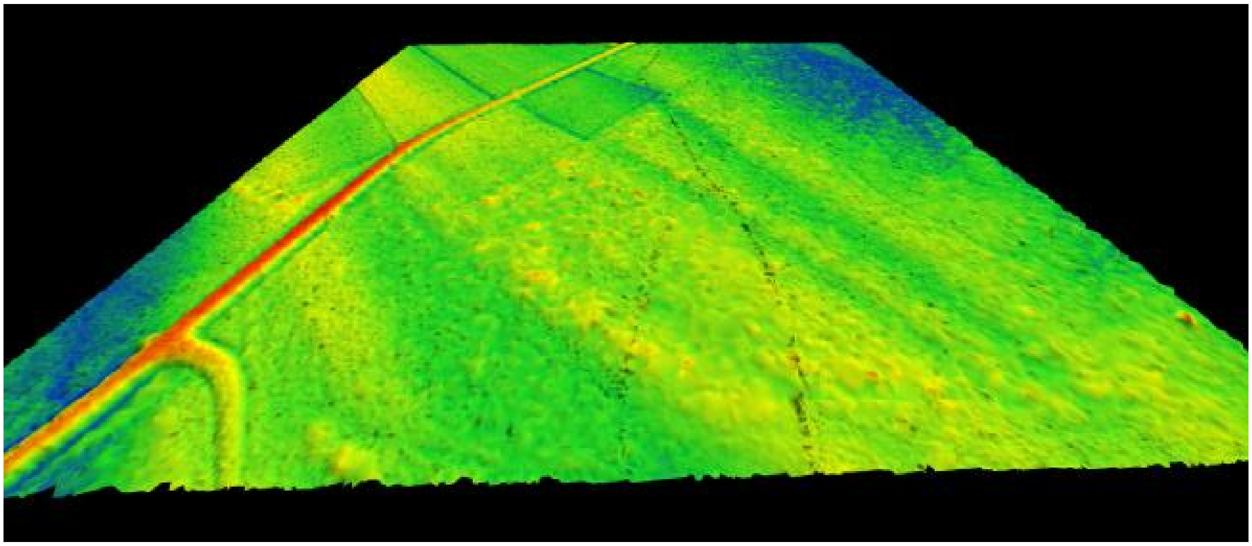

Figure 49 – Scan line edge issues.

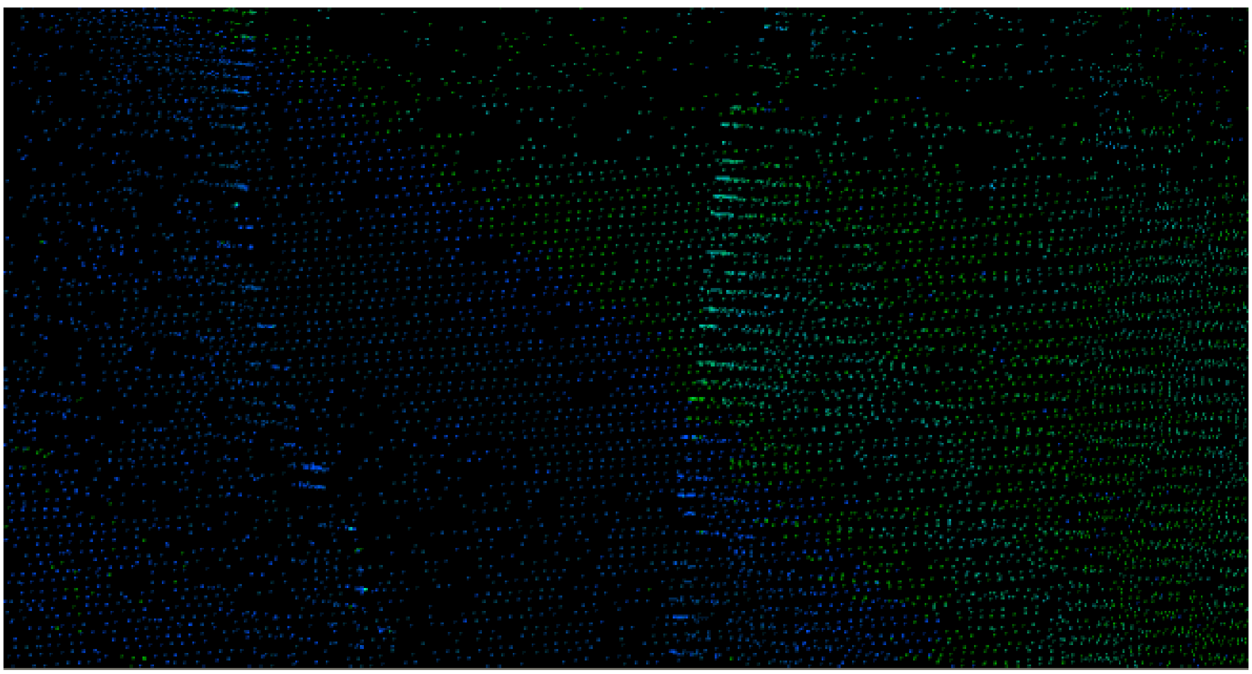

Figure 50 – Zoomed in on ends of scan lines. Notice the groupings of points at the ends of the scan lines.

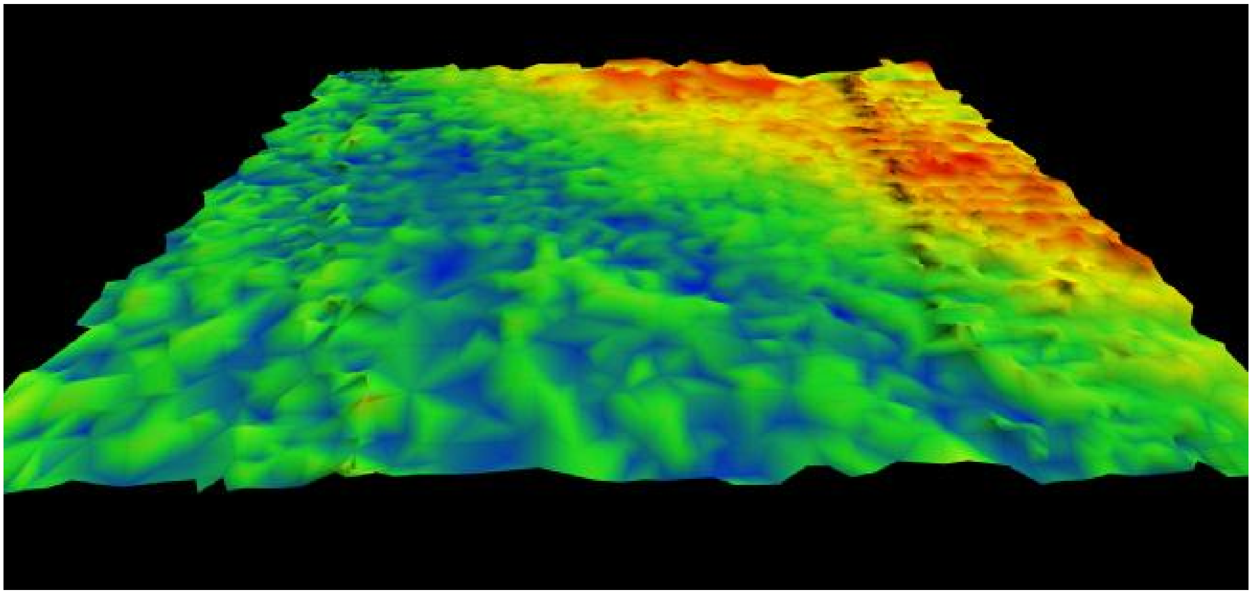

Figure 51 – 3D view of scan line issues. The scan line is slightly elevated on the left hand side.

Conclusion

Dewberry's analysis of the data concludes that it meets the equivalency of 2 foot contours and is of high quality for cleanliness. Hundreds of tiles were scrutinized during this analysis and no errors could be detected with the majority of the tiles. With the errors that were found, our recommendation is not to pursue the rectification of these issues as the data is within the criteria for accuracy as set forth by the RFP and all indications is that it meets the FEMA guidelines of being 95% clean of artifacts. Although "95% clean" cannot be quantitatively measured, our experience indicates that this criterion was met.

Dewberry recommends that the current process be improved to a higher level for any future work. The issue of the scan line edges and overlap were prevalent in some of the tiles tested. This error was usually within the 10 cm range. Two issues arise from this problem: first, the edges of the scan lines were slightly elevated, and second, they introduced a higher noise level of a few cm. This noise level will show a rougher surface. For most large projects this would not be a problem and can even currently be remedied by using the 2 meter grid. This in essence smoothes the surface and eliminates most of these minor anomalies. An additional recommendation is to replace those intensity images that were missing data.

As the independent QA/QC team member, the role of being independent and part of team may appear to be a juxtaposition of terms. However, Dewberry was truly independent without any collaboration other than clarification on some issues with the LIDAR provider (A1) and the post processing company (CCS). Overall, we evaluate this dataset to be excellent.